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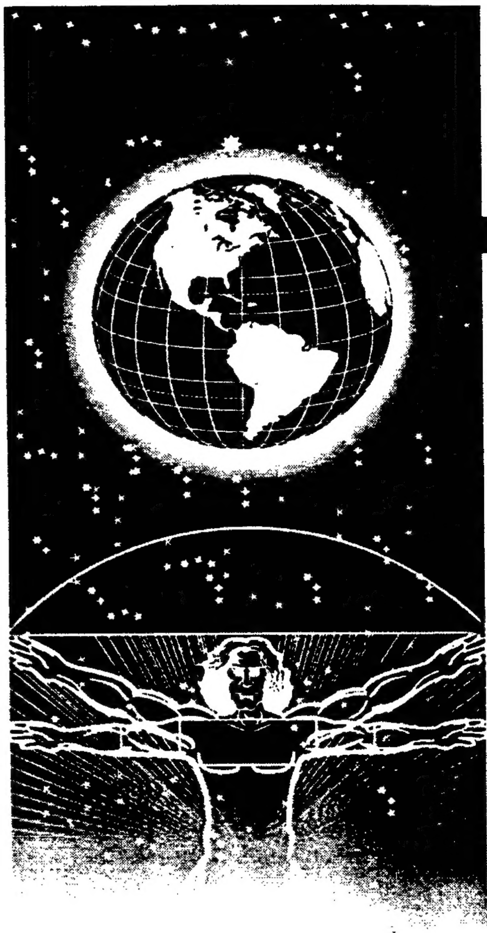

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Demonstration of Radio-Frequency Soil Decontamination: KAI Technologies Demonstration (Volume III of III) Part 1: Pages 1-229

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14. Abstract The Air Force Armstrong Laboratory, Tyndall Air Force Base, Florida, has supported the research and development of Radio Frequency Soil Decontamination. Radio frequency soil decontamination is essentially a heat-assisted soil vapor extraction process. Site S-1 at Kelly Air Force Base, Texas, was selected for the demonstration of two patented techniques. The site is a former sump that collected spills and surface runoff from a waste petroleum, oils, and lubricants and solvent storage and transfer area. In 1993, a technique developed by the ITT Research Institute using an array of electrodes placed in the soil was demonstrated. In 1994, a technique developed by KAI Technologies, Inc. using a single applicator placed in a vertical borehole was demonstrated. Approximately 120 tons of soil were heated during each demonstration to a temperature of about 150 degrees Celsius.

15. Subject Terms Radio Frequency Soil Heating, Soil Vapor Extraction

Security Classification of			19. Limitation of Abstract	20. # of Pages	21. Responsible Person (Name and Telephone #)
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PREFACE

This report was prepared by Halliburton NUS Environmental Corporation, 800 Oak Ridge Turnpike, Oak Ridge, TN 37830 under contract F33615-90-D-4011 for the Armstrong Laboratory Environics Directorate (AL/EQW) (formerly the Air Force Engineering and Services Center), Tyndall AFB, FL 32403-5323.

This final report summarizes the project's Phase I efforts for a field demonstration of the IIT Research Institute's (IITRI) tri-plate capacitor and the KAI Technologies, Inc.'s (KAI) antenna radio frequency heating (RFH) techniques for the enhancement of soil vapor extraction (SVE) for the in situ decontamination of soils.

The work was performed between June 1992 and December 1994. The AL/EQW technical project officers were Mr. Paul F. Carpenter (during the initial stage of the project) and Capt Jeffrey A. Stinson (during the latter stage of the project).

EXECUTIVE SUMMARY

The United States Air Force developed the Installation Restoration Program to assess past hazardous waste disposal and spill sites and prepare remedial actions consistent with the National Contingency Plan for those sites that pose a threat to human health or the environment. Within that program the Site Remediation Division of the Environics Directorate of the Air Force's Armstrong Laboratory at Tyndall AFB, Florida, has supported the research and development of Radio Frequency Soil Decontamination.

Armstrong Laboratory was sufficiently encouraged by the early test results in sandy soils at Tyndall AFB, Florida, and Volk Field, Wisconsin, to pursue larger-scale demonstrations in tight soils that are more difficult to treat. In September 1991, the Air Force Center for Environmental Excellence at Brooks AFB, Texas, contracted Halliburton NUS Environmental Corporation (now Brown & Root Environmental) to conduct pilot scale demonstrations of two different, patented, radio frequency heating techniques at Site S-1 at Kelly AFB, Texas.

The project was divided into three phases the Preplanning Phase, Phase I, and Phase II. The Preplanning Phase, completed in September 1992, included literature review, conceptual cost estimations, design plans and specifications preparation and review, and publication of a final report documenting the results. Phase I included two integrated pilot tests and the preparation of this final technical report evaluating the results of Phase I and the conceptual planning of Phase II. Phase II will include the complete planning and design of a full-scale commercial demonstration of radio frequency soil decontamination.

Radio frequency soil decontamination is essentially a heat-assisted vapor extraction process. Radio frequency energy applied to the soil causes polar molecules, including water and many organic compounds, to vibrate. This vibrational energy is lost as heat. The resulting rise in soil temperature vaporizes both water and contaminants, which may then be removed by application of a vacuum. Extracted vapors may be treated by a variety of methods, depending on the site and the nature of the contaminants. Vapors extracted during the demonstrations at Site S-1 were burned in a flare.

Two types of radio frequency soil heating were demonstrated at Site S-1 from January to August 1993 and 1994. In 1993, a technique developed by the IIT Research Institute that uses a series of exciter and ground electrodes placed in the soil was demonstrated. This technique was tested previously at Air Force sites. In 1994, a technique developed by KAI Technologies, Inc. which uses

an antenna-like device that may be placed in a vertical or horizontal borehole was demonstrated. Halliburton NUS Environmental Corporation provided site preparation services, the vapor extraction system, and supervised and coordinated all other aspects of the demonstrations.

Armstrong Laboratory, Kelly AFB, and the US Department of Energy have contributed funds and guidance for the work completed to date which includes the Preplanning Phase and Phase I. In addition, the Phase I demonstrations are part of the US Environmental Protection Agency's Superfund Innovative Technology Evaluation Program.

Halliburton NUS Environmental Corporation concludes that data gathered during the pilot demonstrations is invaluable to the development of radio frequency heating for the enhancement of soil vapor extraction and can be used to design a commercial scale system and implement remedial activities in accordance with United States Air Force procedures. From lessons learned during the Site S-1 demonstrations, criteria for technology implementation have become apparent that allow the selection of a site better suited to the unique physical and chemical phenomenon inherent in the process. To date only six field tests have been completed. These tests have addressed situations with a wide variance of soil and contaminant characteristics. A phased approach is recommended which would include more demonstrations to plug data gaps and define unknowns followed by commercial scale application. A smaller site with a simpler (more homogenous) soil and contaminant matrix, relative to Site S-1, would simplify the evaluation of results and better define technology applicability.

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1.0 INTRODUCTION

1.1 Overview

KAI Technologies, Inc. demonstrated its in-situ radio frequency heating process (RFH) at Kelly Air Force Base, San Antonio, Texas, IRP site S-1 during the spring of 1994. The technology demonstration was conducted under contract with Halliburton NUS under contract with the Armstrong Laboratory. Environics Directorate, AL/EQW, Tyndall Air Force Base in cooperation with the U.S. Environmental Protection Agency.

The primary objective of the RFH test of the KAI technology was to provide useful information to assist the Air Force in preparing for commercial scale demonstration of RFH decontamination. Other important objectives of this test were the validation of scale-up parameters for a comparison of the capacitance and antenna options of RFH Enhanced Soil Vapor Extraction Technology. Factors addressed during the program were the use of antennas for soil heating and vapor extraction, evaluation of contaminant movement through soil, and the removal of volatile organic compounds from the soil.

The KAI mobile RF system was prepared and ready to start heating within six working days of the systems arrival on site. The KAI RF heating system successfully delivered 15,549 kilowatt hours of energy to the heating zone within a total time span of 51.3 days. The RF generator developed RF power at a 19.93 kw/hr rate and was delivering this RF energy to the soil for 94.54% of the available testing period. The efficiency of RF energy transfer to the soil was measured directly during the heating period and exceeded 85% during operation. Successful impedance matching of the buried antenna occurred throughout testing and it was found that the antenna could be successfully tuned at all depths of the well. This is a significant point from a commercial system operation viewpoint. It means high coupling efficiency of RF energy to soil is maintained automatically as the antenna is moved to different heating zones during operation.

A dual antenna system was employed for this test. Measurements of mutual coupling between antennas during the heating period provided information on the removal of moisture. A significant change in the mutual coupling during heating occurred and demonstrates moisture and contaminant removal in a quantitative way. It will be an important diagnostic goal for commercial operation but will require development.

The program accomplishments summarized below are from the perspective of the RF heating system operation.

1.2 Accomplishments

- **The uniformity of soil heating within test volumes** - The heating program provided an extensive data set of temperature profiles.

  The initial heating rate of the test and several aspects of the SVE configuration produced thermal records that suggest that there are significant regions of uniformity with soil

temperatures elevated well above 100 degrees centigrade (C).

There were regions, at a 3-foot radius from the antenna that exceeded 120 degrees C in the context of SVE flow influences. These infrared (IR), indirect temperature profiling measurements suggested that adjacent soils may have had localized heating temperatures for hydrocarbons at or above the 150 degree temperature goal of the program. The highest measured temperature for the program was a direct, peak measurement of 233.9 degrees C by a fiber optic temperature probe located on the outside of the heating well liner wall. The sustained high temperature readings in this region suggested a flow of a hot liquid into the volume surrounding the well liner sensor.

- **Commercial Operation** - The later portion of the heating program (21.3 days) provided operating statistics that can be used for commercial system cost and operation projections.

1.3 Modifications to Program Cost and Operation - This program was executed within the framework of several modifications. The most significant are:

- The on-site heating zone was defined as one-half of the volume originally planned as the treatment zone. This was due to the choice of a 27.12 MHz frequency to heat two smaller, 10-foot thick, adjacent volumes faster that the 13.56 MHz alternative ISM frequency. The 13.56 MHz frequency would have required more on-site heating time but would have covered the full 20-foot thick treatment zone.

- The RF heating applicators were positioned high in the well liner borehole spanning from 5 ft. down to 13 ft. within the heating zone.

- Initial delivery of 3-phase AC utility power to the RF heating system limited the RF energy generation rate. For the first 22 days of the program the system generated RF energy at an average rate of 9.42 kW/hour as opposed to the last 21.3 days of 19.93 kW/hour.

- The initial low power delivery rate did not allow the sequential heating of boreholes A1 and A2 in a manner that would allow their heating patterns to overlay as an approximation of a dual applicator, dual RF generator system.

- The design of the SVE system prevented meaningful conclusions being drawn about the measured changes in TRPH VOC and SVOC concentrations inside and outside the treatment zone as a result of RFH treatment.

1.4 Conclusions

The KAI mobile RF system performed as expected and provided significant RF energy coupling to the soil. Site set-up time was relatively fast and efficient. The applicator system (antennas) allowed for flexibility in the in-situ application of RF energy at selected depths. The coupling efficiency or energy transfer to soil was high (>85%). High efficiency is easily maintained as the applicator assumes different borehole depths for commercial scale uniform heating.

Radio frequency energy desorbs and mobilizes the contaminants more effectively than heat conduction by steam or hot air because thermal activation of the contaminant occurs at the molecular level throughout the RF treatment volume. The dipole-dipole bonding between contaminant molecule and soil particle is thermally agitated at the bonding site by the RF energy.

This result has significant implications for commercial RFH systems operating with tight soils. SVE efficiency appeared to increase substantially during the demonstration.

2.0 RF HEATING SYSTEM CONFIGURATION

KAI Technologies employed a mobile RF heating system, designated Rig #1 for this program. The system arrived on site on 28 March with all of the essential components for site setup and operation.

Figure 1 is a drawing of the mobile system with the overall dimensions of the truck and trailer combination. The trailer is a fifth wheel, gooseneck style, 28 ft. flatbed with a front mounted storage area and a removable 8 ft. x 8 ft. x 20 ft. removable steel shelter. The tow truck is a basic 1-ton pickup modified to tow the trailer as a combination vehicle with a licensed GCVW of 30,000 lbs. The truck is equipped with a roof rack suitable to carry 30-ft. applicators and tubes to the site and is an integral part of the site support strategy.

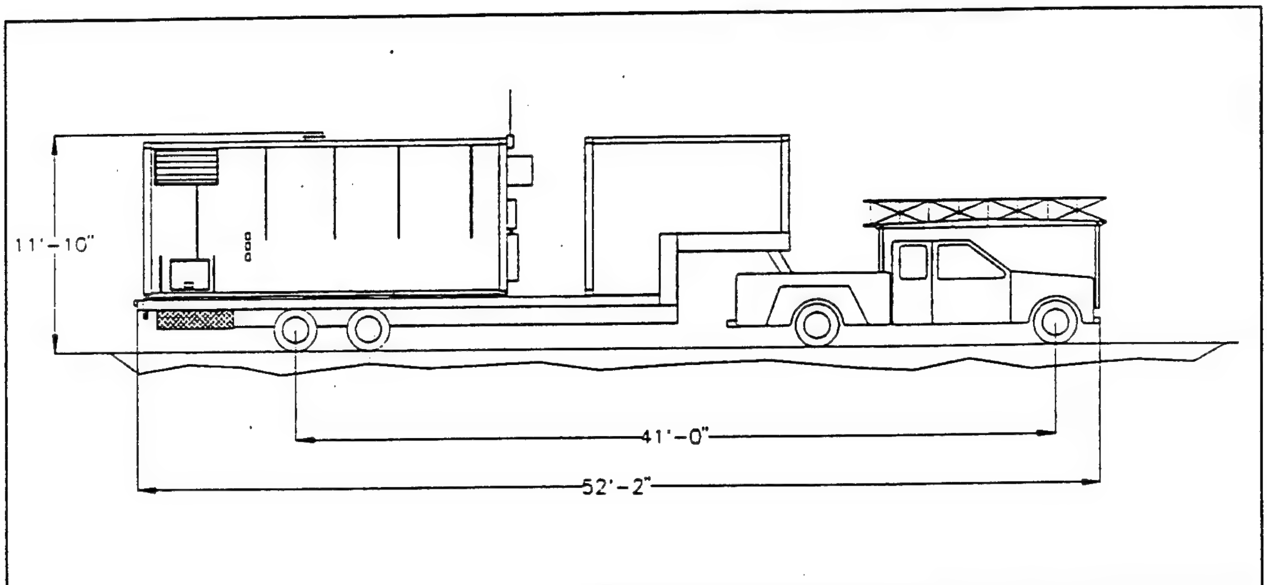

Figure 1 Dimensions of the KAI mobile RF Heating system configured for travel.

Figure 2 is a photograph of the system in-route to Kelly AFB. The RF heating applicators and transmission lines are carried in the trailer's four under-deck storage bays. Additional 20-ft. sections of RF transmission lines were carried on the roof of the shelter and the 10-ft. sections of the aluminum applicator emplacement towers were secured on the over-the-cab roof rack of the pickup truck.

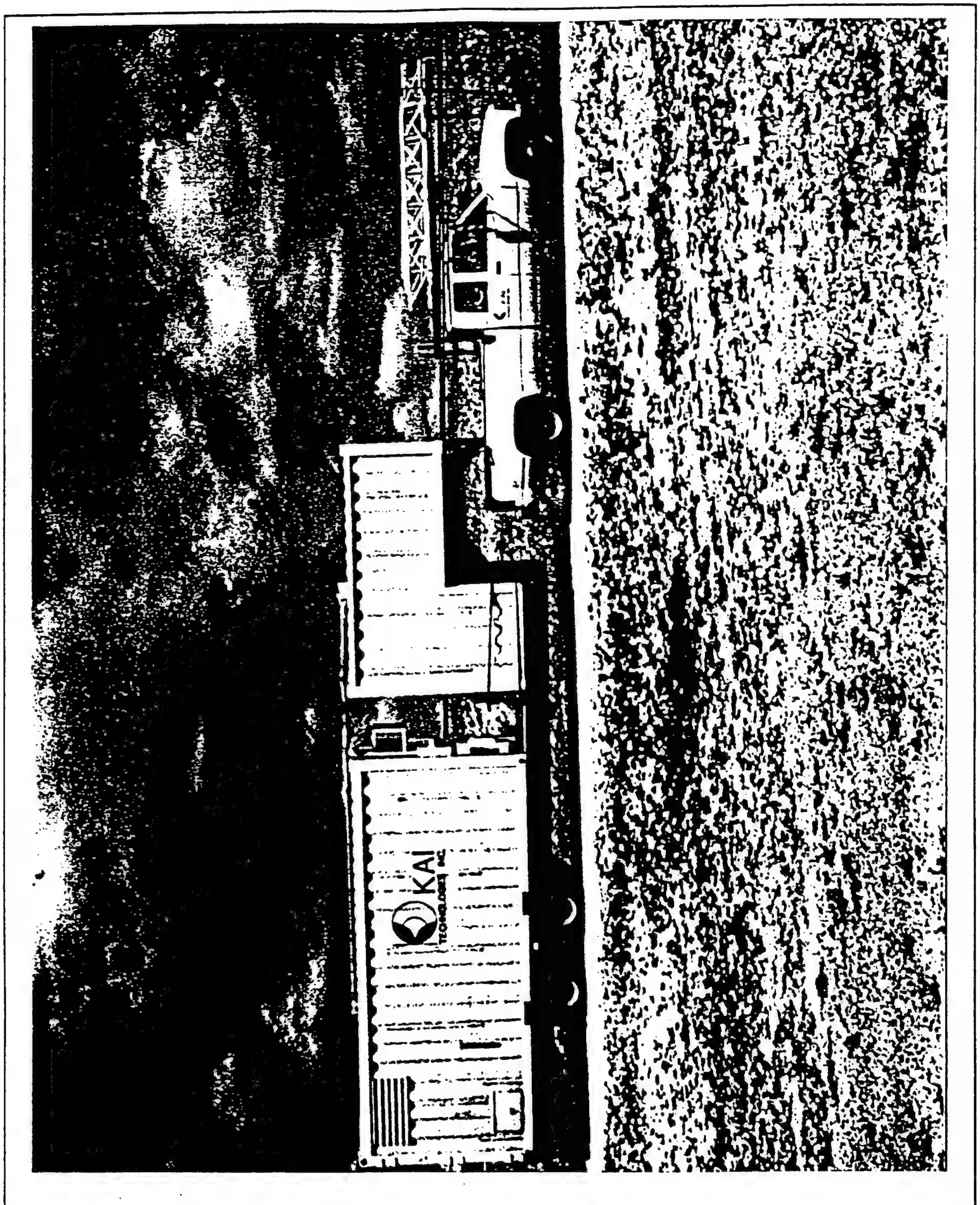

Figure 2 Photo of KAI mobile RF heating system.

2.1 Block diagram of the Basic RF Heating System - The basic RF heating system is diagramed in Figure 3 below. The figure outlines the component groups of a basic radio frequency (RF) heating system. The system power is supplied from the local utility power grid or a diesel generator through the 3-phase power distribution panel. The panel supplies power to the RF generator and a cooling blower as well as lighting, air conditioning and instrumentation. The power system also includes an uninteruptable power supply for critical instrumentation and control functions. The RF Generator supplies power through the transmission lines and the matching network to the RF heating applicator or "antenna" which typically radiates 95% of the energy it receives into the surrounding medium (soil, rock, oil). The system controller is interfaced to all elements of the system. Site environmental monitors can detect overheated components, energy leakage and component tampering. The controller is capable of transferring the complete monitoring of the system to a remote location through a phone line or a cellular telephone data link. Alarms and system status message can be set via the telephone link or messages can be sent as pre-recorded voice messages via the same UHF radio frequency communications transceiver used for site communications. On-site diagnostics instruments periodically measure the system's performance and verify operation.

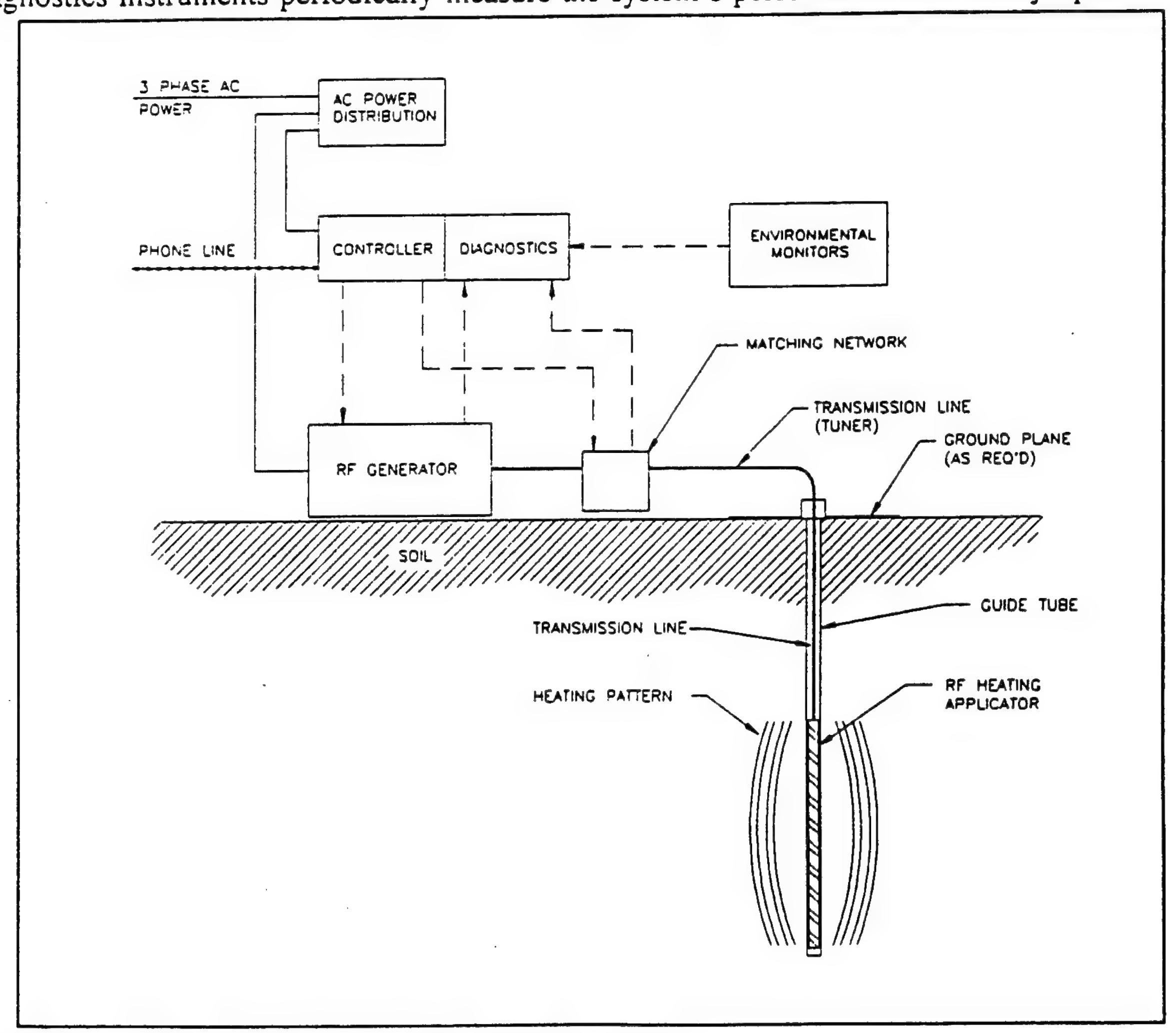

Figure 3 Block diagram of an RF heating System.

For the Kelly program the RF Generator was controlled to alternately drive one of the two applicators that it was connected to. Figure 4 shows this setup in block diagram form.

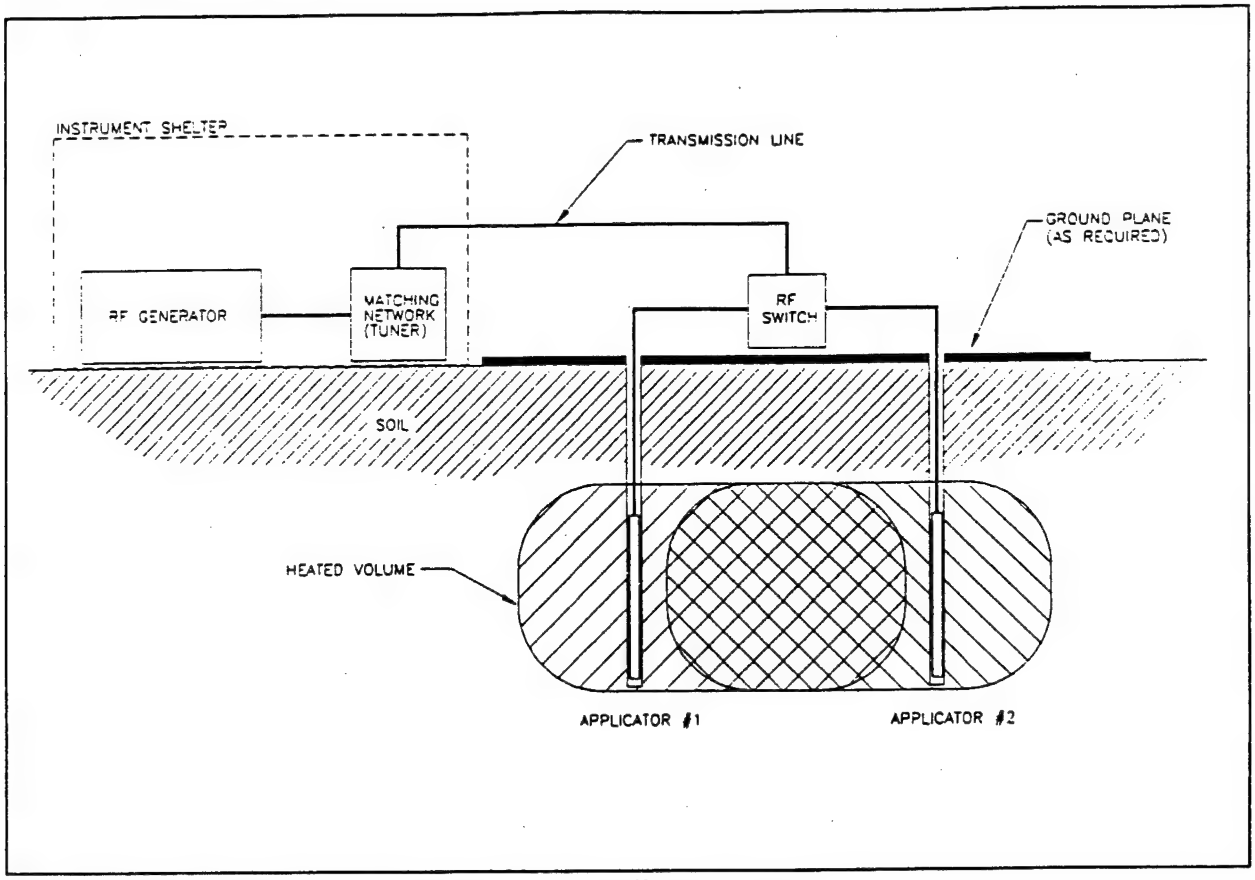

Figure 4 Block diagram of a switched, two applicator system.

Figure 5 is a detailed diagram of the high power and low power RF transmission paths within the instrument shelter. 3-phase AC power is converted to 27.12 MHz radio frequency (RF) power within the RF generator. The RF is power level is measured in directional coupler CPL #1 and is switched to either the 25 KW dummy load for system tests or to the matching network (tuner) by RF switch SW #1. The matching network is adjusted to couple the load presented by the transmission line and applicator to the output circuitry of the RF generator. The output of the matching network passes through RF SW #2 and is measured by directional coupler CPL #2 as it passes out of the instrument shelter. The transmission line from the instrument shelter is connected to RF SW #3 which directs power to either RF heating applicator #1 or #2.

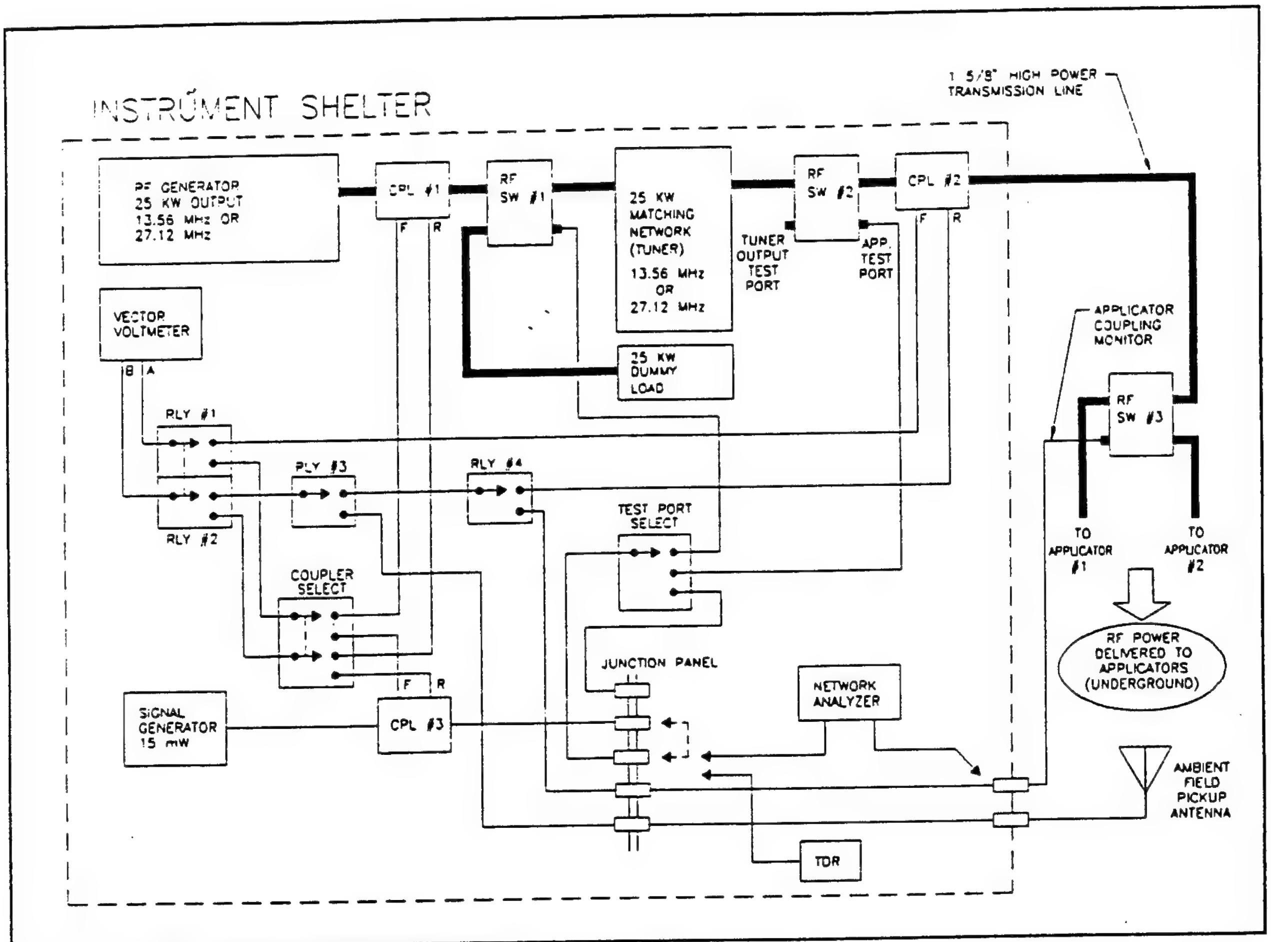

Figure 5 RF heating system transmission line paths.

The figure also details the low power measurement paths of the system that are used to control and monitor the application of the RF to the heating zone. The key instrument for real time power monitoring is the vector voltmeter. The voltmeter inputs are switched to measure the forward and reflected power at each of three directional couplers within the system. The voltmeter, which is technically a dual channel, phase discriminating, reference tuned radio receiver, is also used to measure the ambient RF emission of the heating site.

In this capacity the voltmeter serves as a safety/environmental monitor and is capable of alerting the operator of increasing RF emission at the fundamental heating frequency from the system. The voltmeter or an RF power meter (not on diagram) were also configured to measure the in-soil, incident power received by the non-heating applicator. This measurement is a real time indication of the power radiated by the heating applicator and the degree of water and contaminant removal from the heated volume between the applicators. In this mode the vector voltmeter functions as a site diagnostic tool.

The system also contains several diagnostic instruments. The signal generator is used in conjunction with the vector voltmeter and the control computer to form a stepped network analyzer. A portable network analyzer can be used to more rapidly make high resolution, swept frequency measurements of system and applicator parameters.

The junction panel and the two selector switches are used to allow a quick manual setup for measurements. The measurement paths are selected by the test port select switch. The applicator test port of RF SW #2 is the direct measurement path to the applicator for measurements of its parameters by the network analyzer, time domain reflectometer (TDR) or high voltage megger.

Figure 6 is a view of the inside of the instrument shelter. The RF Generator is visible on the right. The instrument rack is on the left. The control panel for the matching network is on the upper side of the wall.

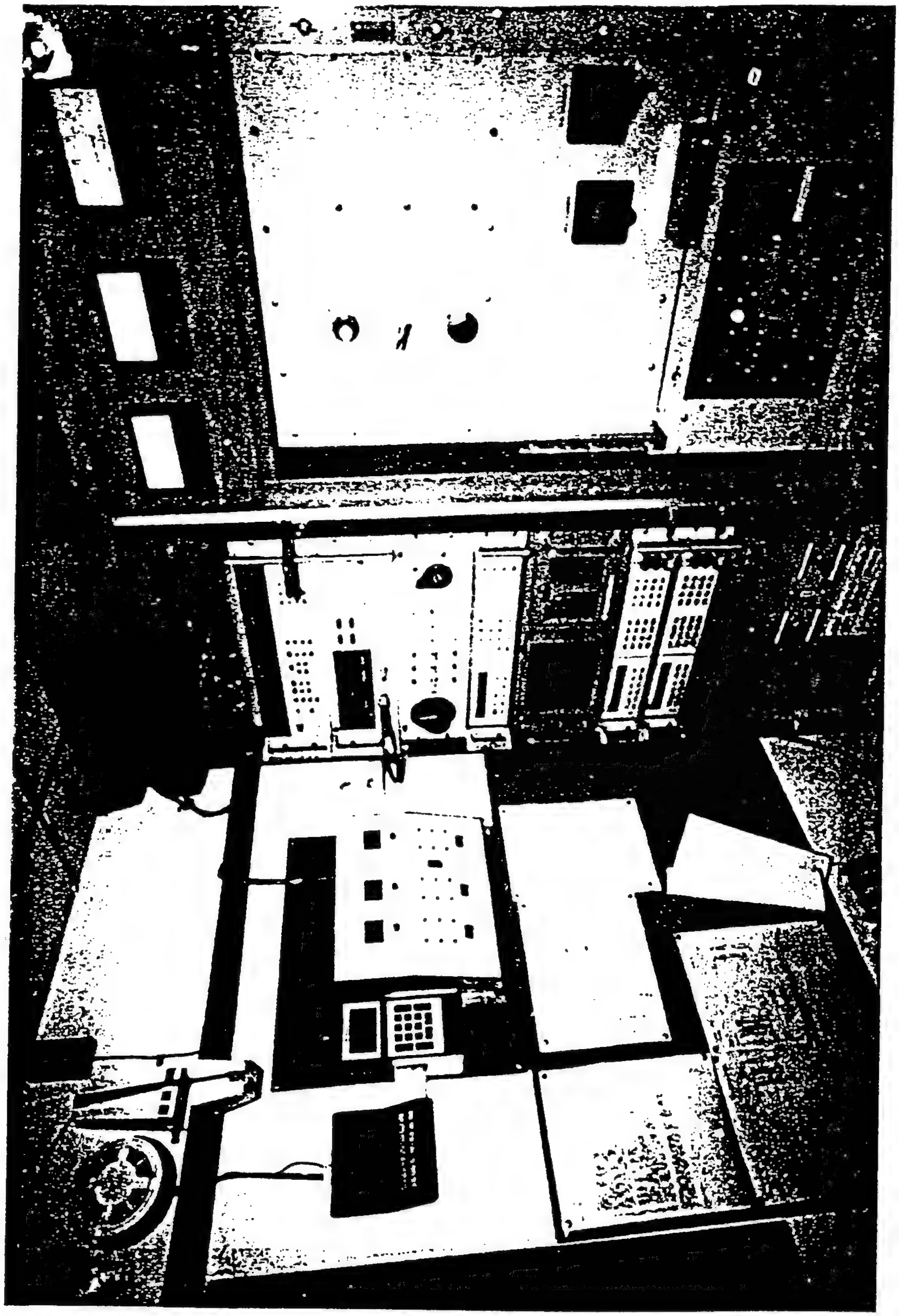

Figure 6 View of instrument rack and RF Generator inside of instrument shelter.

2.2 The RF Heating Applicator - Figure 7 is a diagram of the 3.5" diameter applicator assembly (KAI-0690-30) with the tuning dimensions used for the Kelly program. The RF Applicators are proprietary, KAI developed, devices.

The RF applicator is a dipole-style antenna with a nominal matching impedance of 50 ohms. The applicator is constructed with aluminum, stainless steel, Teflon®, ceramic, brass and copper components. The applicator is connected to the RF generator with nitrogen pressurized, 1-5/8 in. rigid copper transmission line sections. The assembly is lifted by a transmission line clamping collar and wire rope assembly that is not shown here. The 8 ft.-3 in. dimension for the radiating elements is set by interactive on-site measurements. The applicator extension arms are threaded to allow changes in length. The nominal heating span corresponds to the dipole structure formed by the extension arms. In practice the heating pattern typically extends, with lower intensity up the transmission line toward the clamping block.

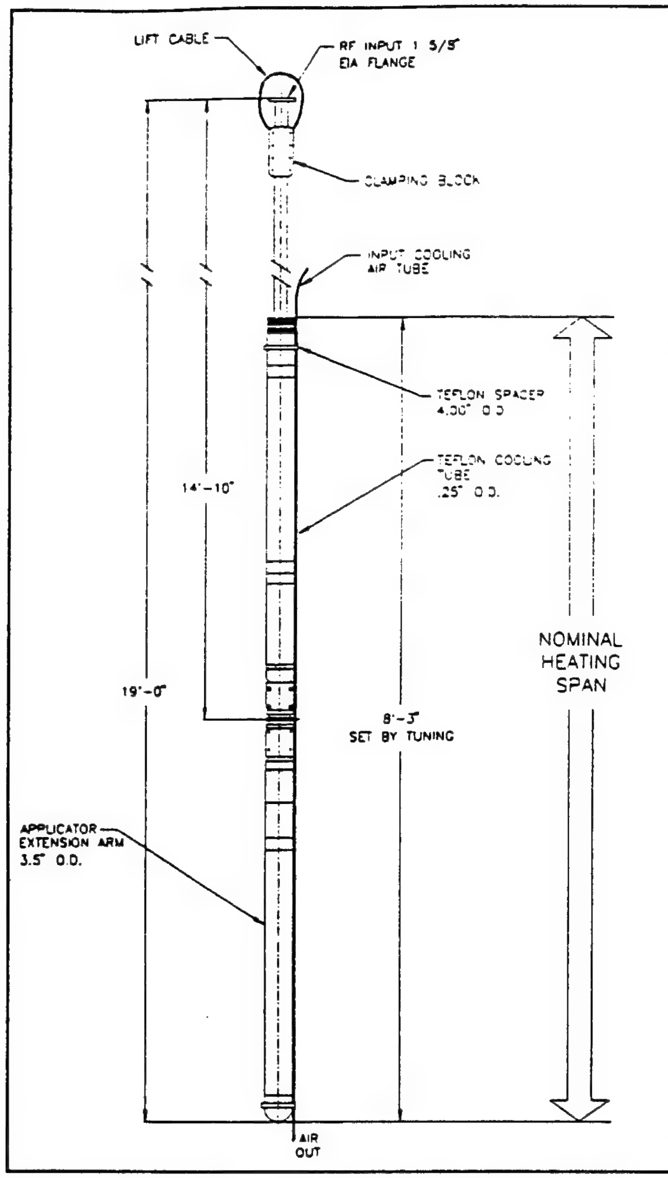

Figure 7 A 3.5 in. diameter RF Heating Applicator specifically tuned for operation at 27.12 MHz at Kelly AFB.

The 1-5/8 EIA connection flange is shown at the top of the figure. One of the four 0.25 in. diameter Teflon® cooling tubes are shown attached to the applicator by the 4 in. diameter Teflon® centering spacers. The tubes are used to cool the walls of the well liner (guide tube) with dry compressed air (e.g. well A2 for the Kelly program).

The applicator is inserted in a well liner with a nominal ID of 4.3 in. The liner is used to isolate the applicator from the surrounding contaminated soil and allow for easy repositioning of the applicator within the contaminated zone..

2.3 RF Heating Site layout - The RF system layout used for the Kelly program is shown in Figure 8. This view is limited to key components. Items such as nitrogen lines, compressed air cooling lines, fiber optic temperature monitoring cables and extended ground radials have been left out for simplicity of display. The heating and treatment zone boundary used for soil analysis is outlined.

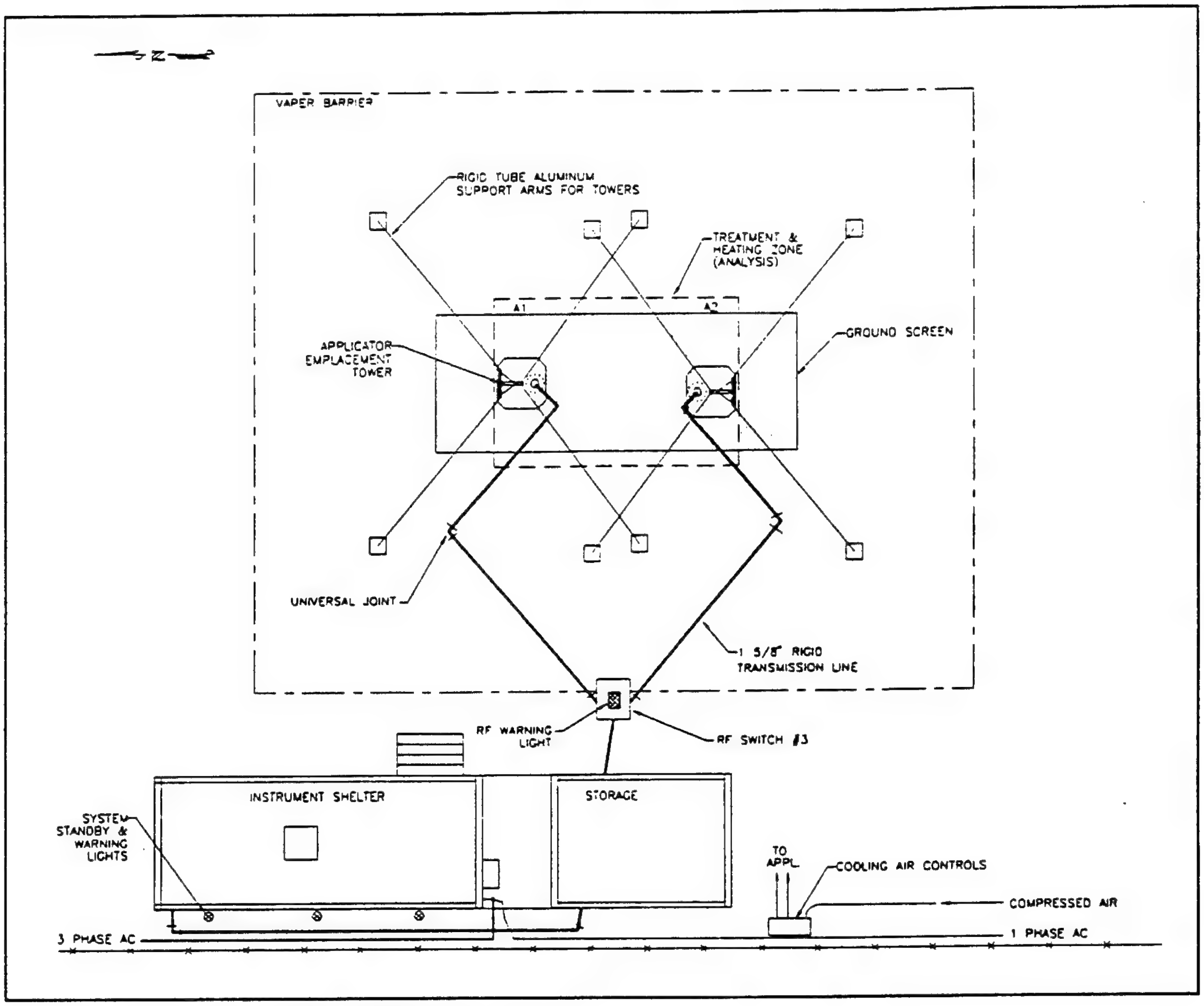

Figure 8 Plan view of RF heating site layout.

This view of the site shows the relationship of the instrument shelter to the vapor barrier and the test area. The fence line of the site is shown along the bottom of the figure where the 3-phase and 1-phase AC power feeds are shown. The well liner cooling air control panel is shown with the compressed air line from the site's diesel driven air compressor is shown. The RF transmission line from the instrument shelter feeds RF switch #3 which selects either applicator #1 or #2. The transmission lines are pressurized in zones with nitrogen or dry compressed air. The transmission lines are joined with dual right-angle connectors to create universal joints at points that require movement as the applicator position is adjusted within

the well. The portable aluminum applicator emplacement towers are located above each heating well. The towers are mounted on a 3-foot x 3-foot ground plane base that is electrically connected to the ground screen and four copper clad steel ground rods. The four rigid aluminum telescoping support arms are terminated in pads that are staked with one ground rod and three 18-inch spikes. The towers were self supporting with a height of 20 feet. The towers are capable of extension to 30 feet to accomidate a wide range of applicator positioning with a single transmission line configuration.

Figure 9 is a more detailed view of the ground screen with the grounding radials shown. The grounding plane in this program is used to provide control surface electric field (E-Field) emissions and to stabilize the tuning of the applicator for heating positions located near to the surface. Figure 8 shows more details of the ground plane and its relationship to the temperature test wells.

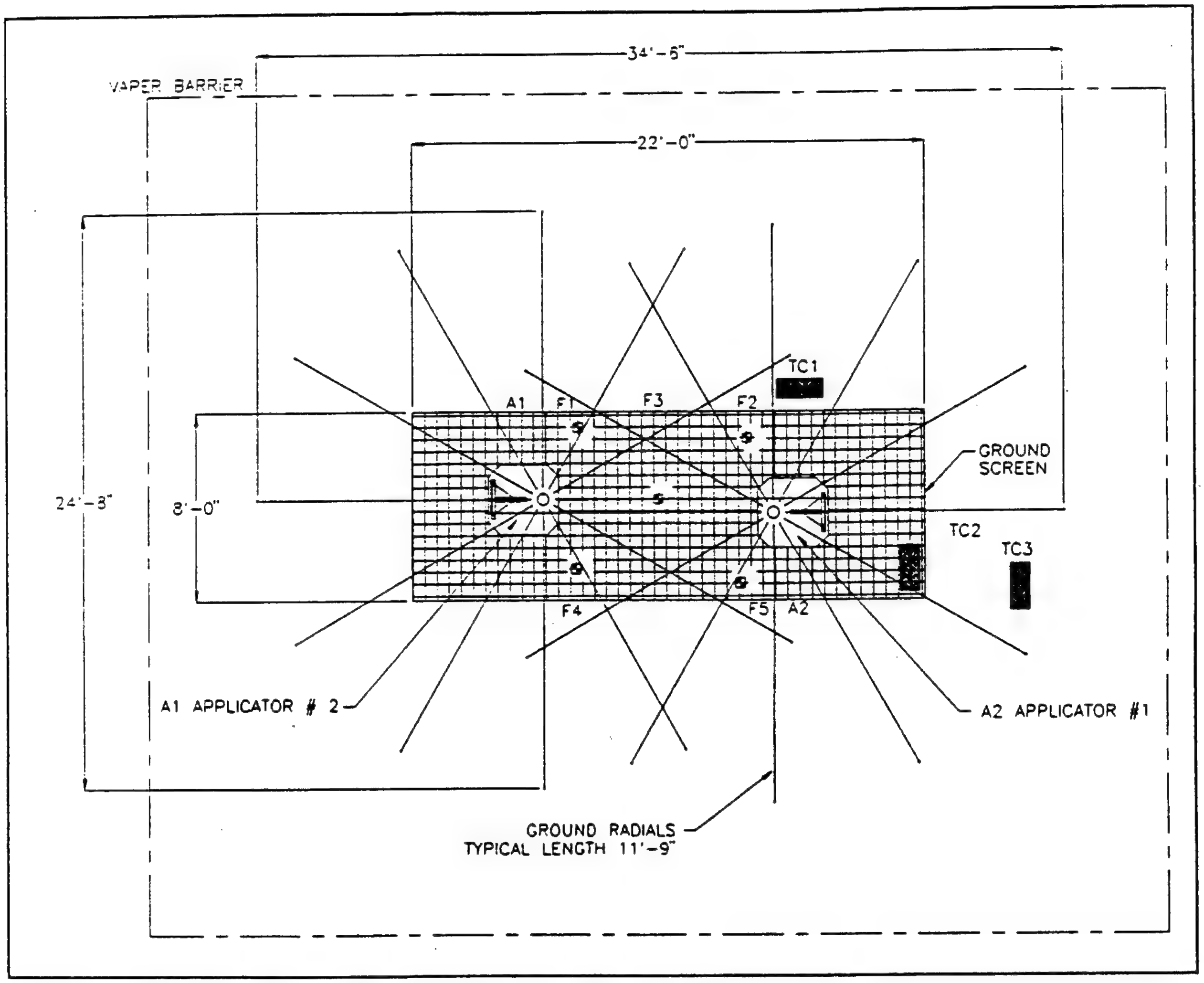

Figure 9 Detailed view of the ground plane with radials.

Figure 10 is a view of applicator #1 suspended from the 20-ft. high portable emplacement tower positioned over the A2 well entrance.

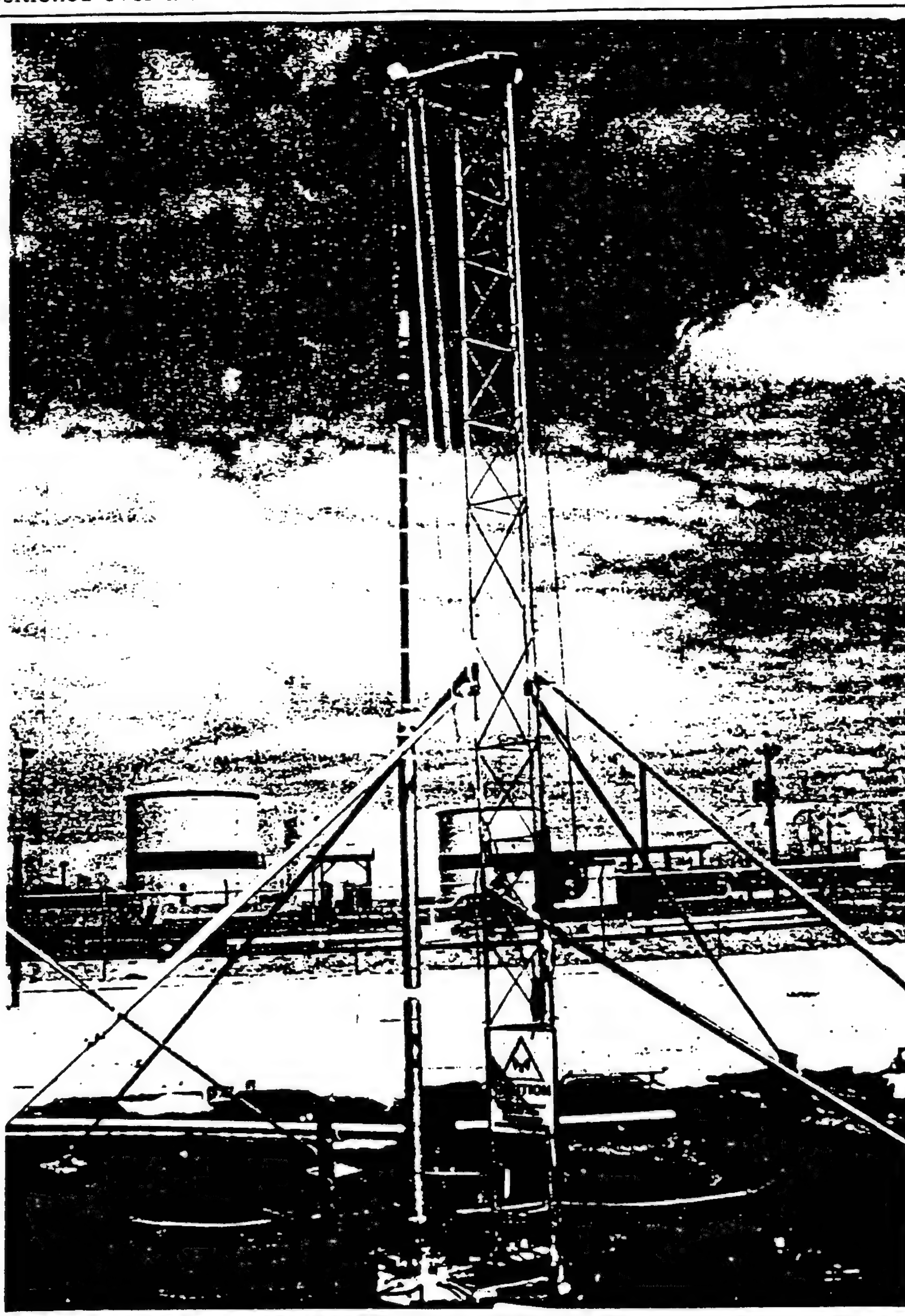

Figure 10 Applicator suspended from emplacement tower over well A2.

Figure 11 is a view of the site viewed from the Northwest corner looking to the Southwest. The SVE system and flare are visible in the upper center of the photo.

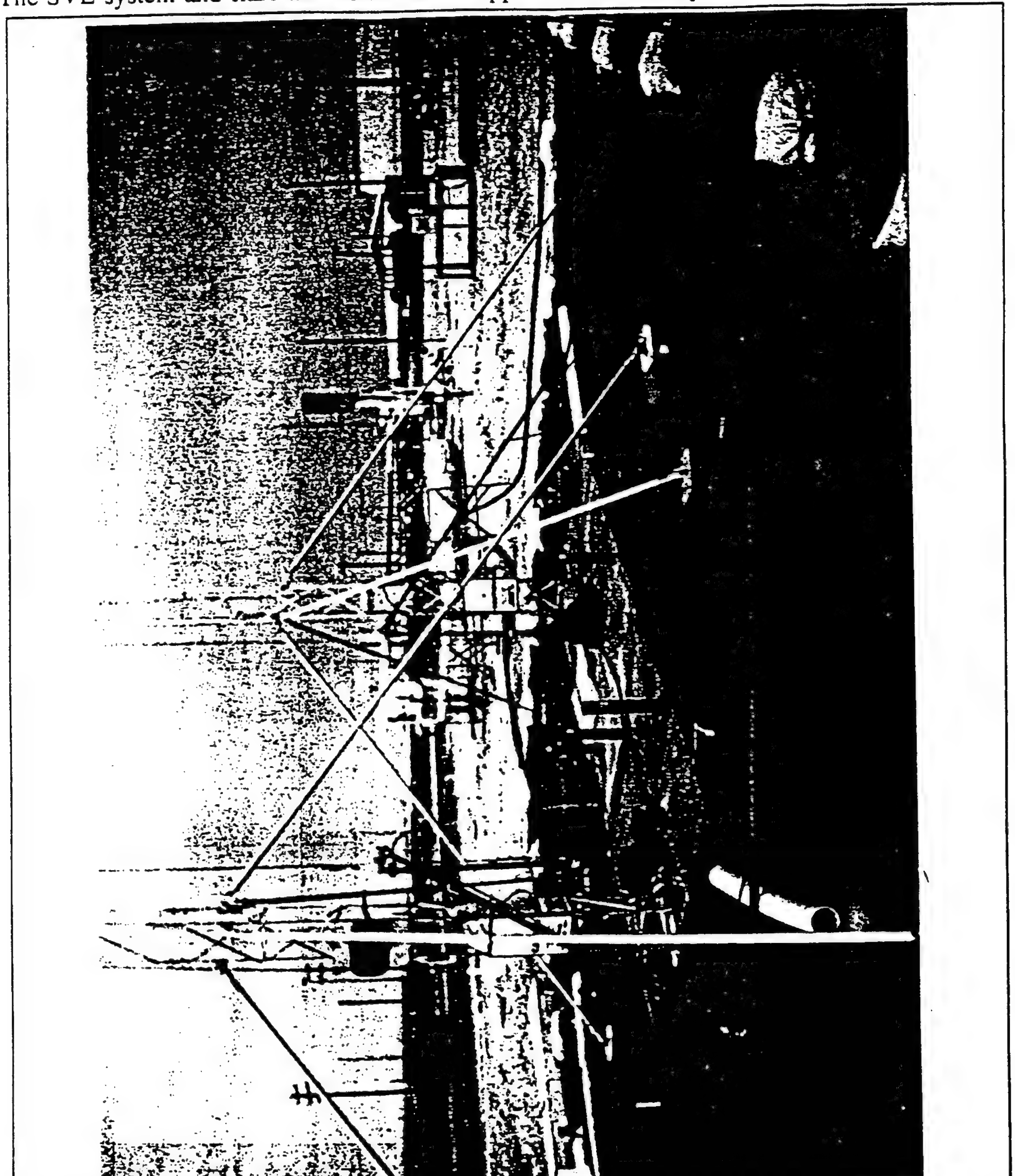

Figure 11 View of operating site with towers and transmission lines in place.

2.4 **Site layout with boreholes and SVE description** - The section is an assembly of drawings which integrate the details of the RF heating system, the sensor system and the soil vapor extraction (SVE) system. Figure 12 is a drawing that is based on the actual installation survey of the wells drilled at the site. The "E" wells are part of the SVE system. The "F" wells are used to record temperature profiles and magnetic field profiles of the Treatment and Heating Zone. Wells A1 and A2 are used to insert the RF heating applicators. The section lines shown on the diagram are used to define the cuts for site cross-section drawings. The drawings were used temperature analysis.

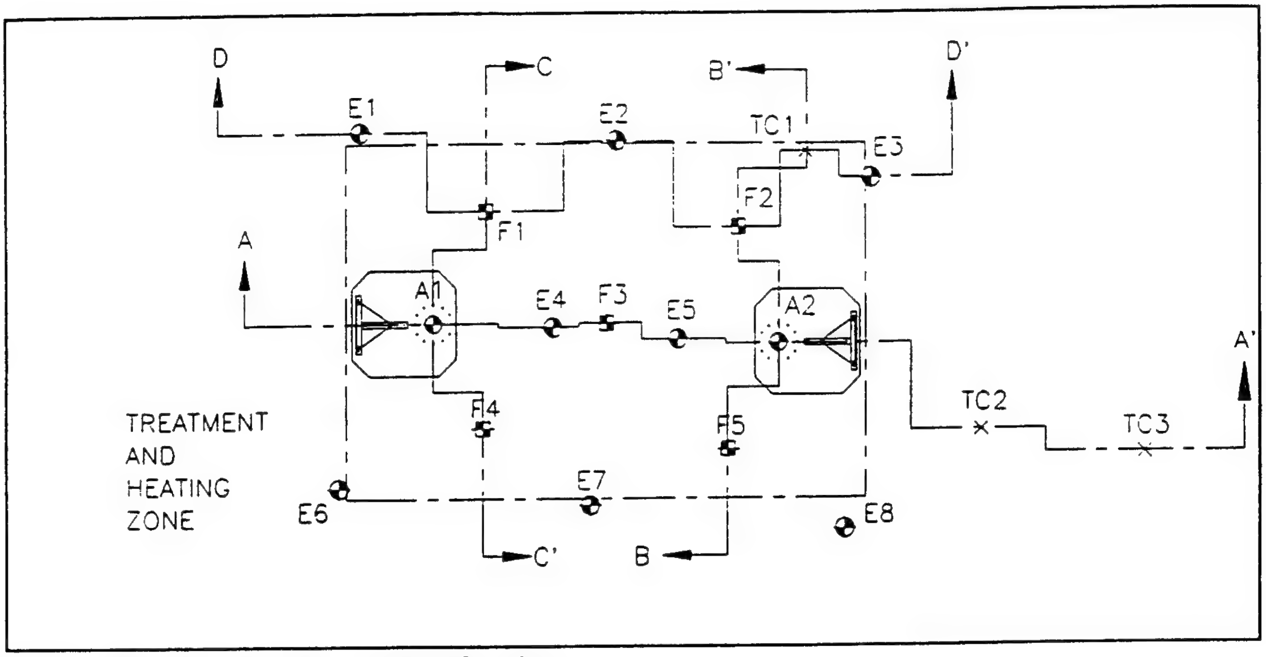

Figure 12 Actual layout of wells for site.

Figure 13 is a plot of section A-A'. In addition to the well profiles the drawing includes the locations of the five possible locations of the fiber optic sensing probes shown as "✦" points. The temperatures recorded by these probes were logged every 20 seconds by the control system computer. The FO CH 21 (fiber optic channel 21) and FO CH 22 sensors are located inside of a thin-wall Teflon tube, packed in sand and positioned on the outside of the well liner at a depth of 10.5 feet. These sensors were the primary temperature measurements for the control of the heating system. The measurements were used to determine if the heat developing in the surrounding soil was heating the liner to a damaging temperatures. The FO CH 23 and CH 24 sensors inside of the well liner were placed against the liner wall at the top of the used to monitor the effectiveness of the compressed air cooling of the inside liner wall. The FO CH 23 sensor position was used on several occasions to observe trends in the wall heating of monitor well F3.

The heating applicators are show in their operating positions in A1 and A2 within the heating zone. E4 and E5 are extraction wells used by the SVE system. The black portion of the well diagram represents the solid walled region of the extraction tube. The lower, open section was screened to allow a vacuum to be drawn on the heating zone.

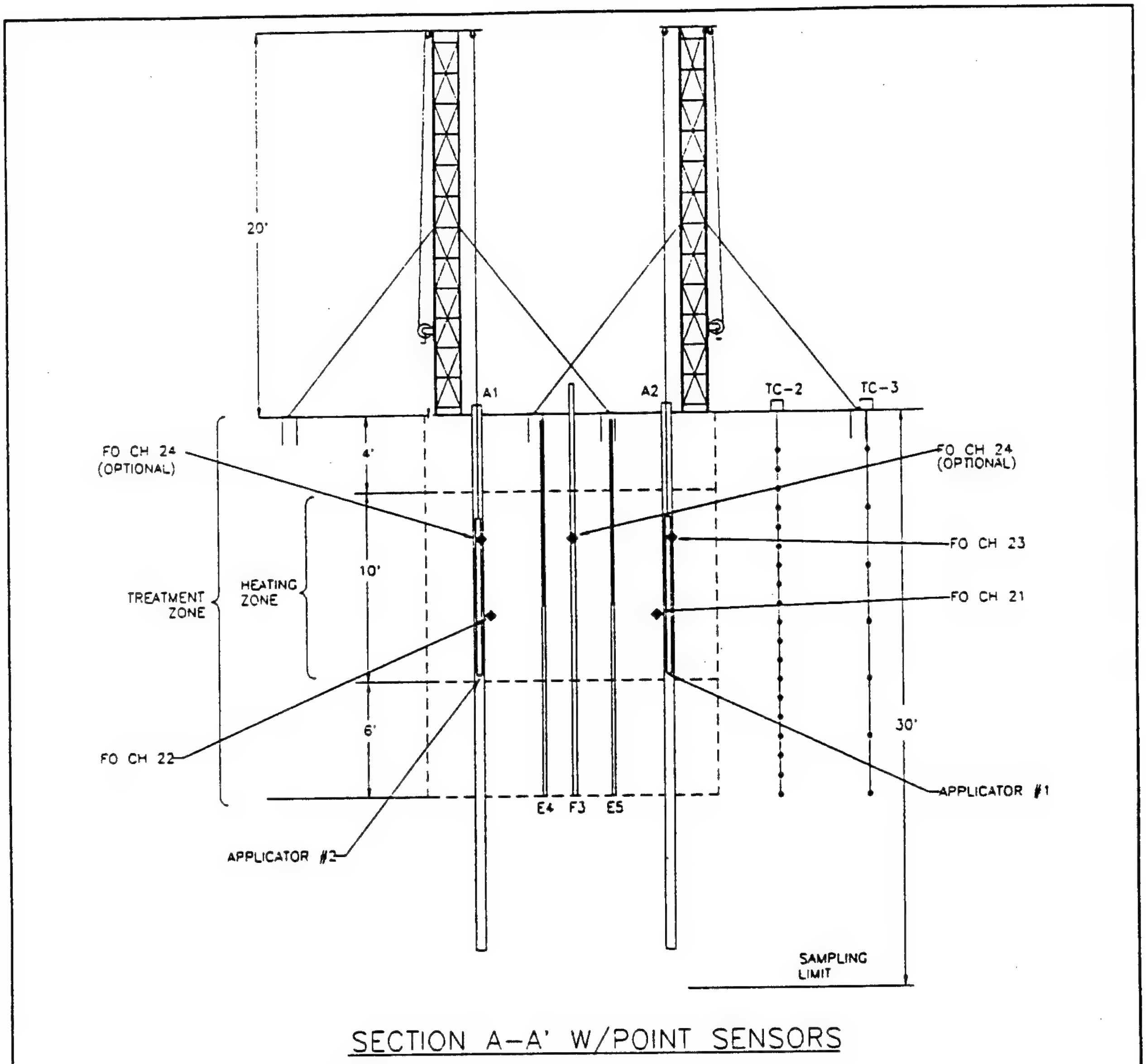

Figure 13 Site cross section A-A' with sensor positions shown.

The information in Figures 12 and 13 is brought together in a 3-D perspective drawing in Figure 14. In this figure the heating applicator wells (A1, A2) are show in relation to the measurement wells (F1 through F5) and the thermocouple strings (TC-1 through TC-3). The heating zone is shown within the treatment zone.

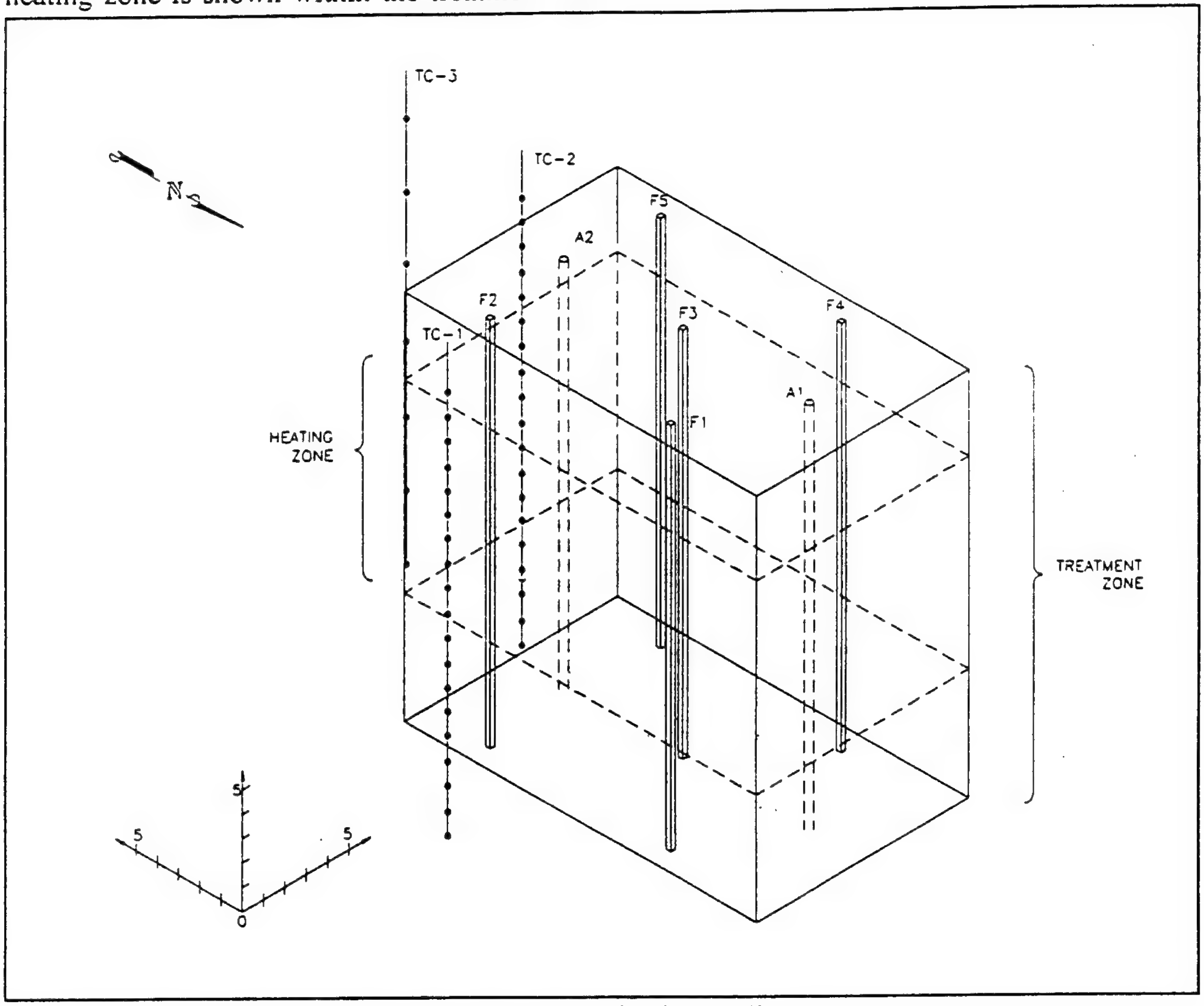

Figure 14 Isometric view of applicator and monitoring wells.

Figure 15 is an isometric view of the extraction system with its major piping features shown relative to the vapor barrier. Figure 16 is an expanded view of the treatment zone. This view allows a detailed visualization of the SVE extraction system. The clear tube areas of wells E1 through E8 are screened for air passage. The E1 through E3 wells are used generally for extraction but starting on 23 May they were used for passive injection of air. The E4 and E5 wells were used for extraction in the middle of the site. The E6 through E8 wells were used for passive injection. During most of the program only the E8 well was open to the outside air.

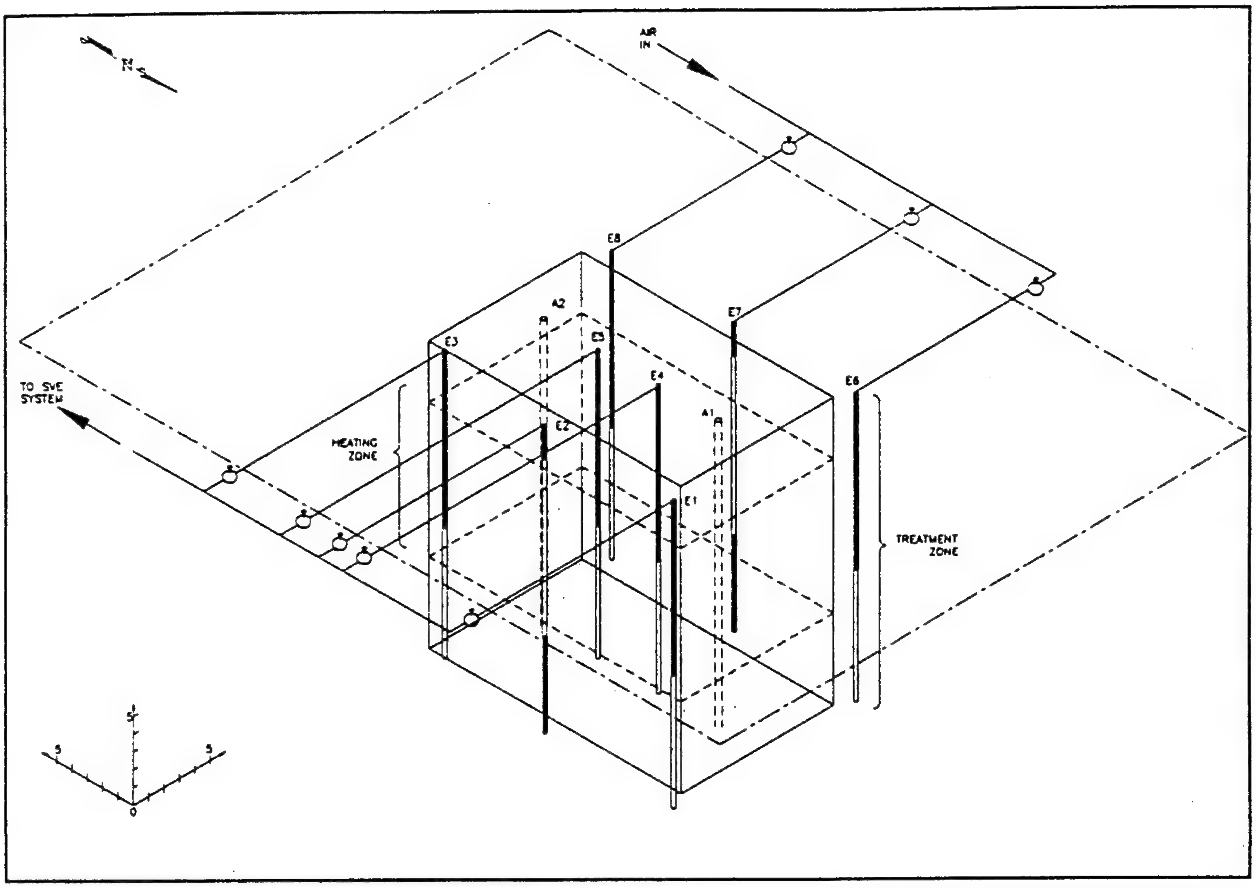

Figure 15 Isometric view of SVE wells with piping.

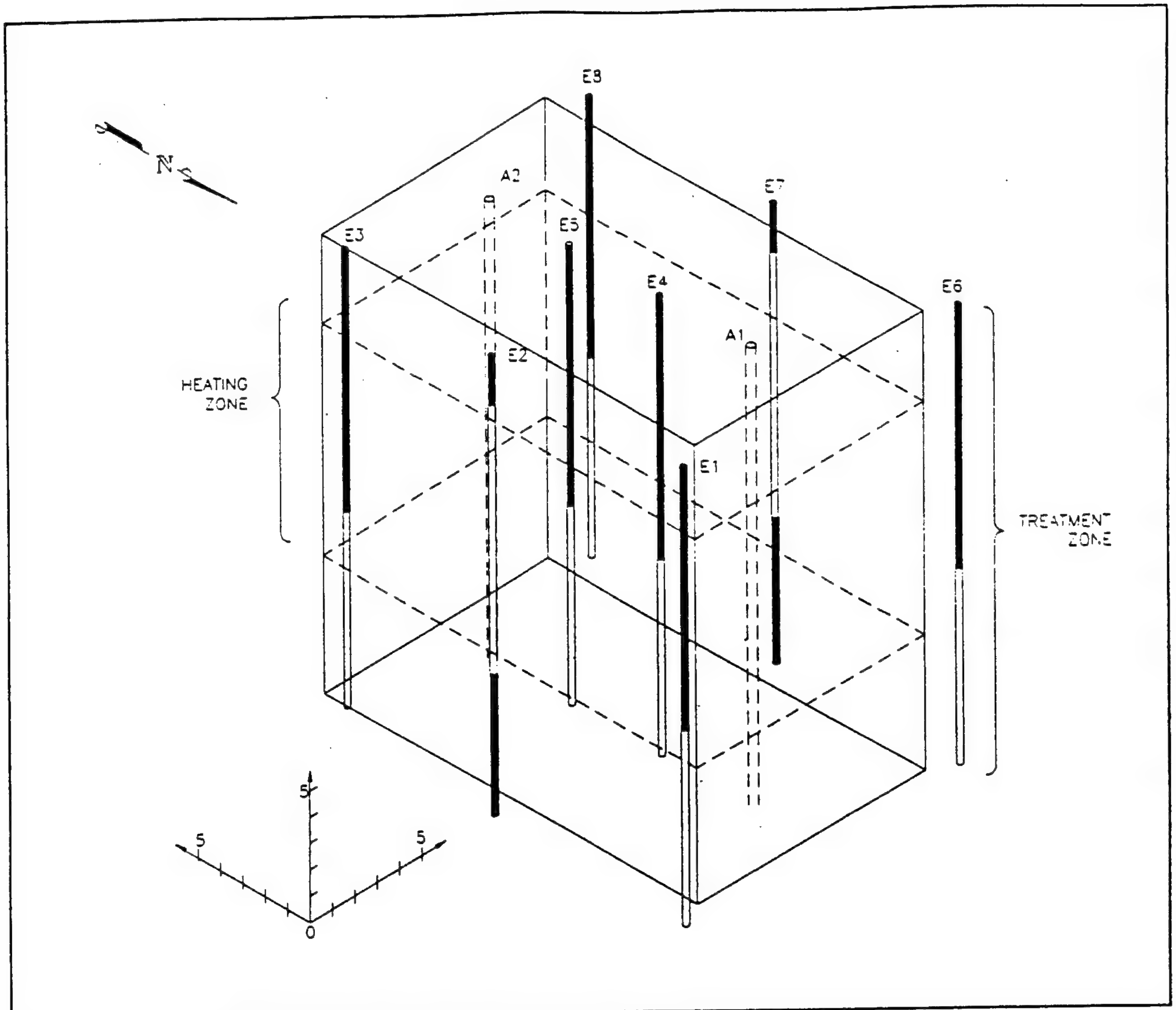

Figure 16 Enlarged isometric view of extraction wells.

2.5 Detailed RF Heating System Specifications - This section provides technical details on a number of system components that are listed in the block diagrams. Commercial equipment items are listed by make and model. The equipment grouping described here is appropriate for a full-scale pilot testing system or the master control unit for a two or four generator phased array[6] RF heating system. The diagnostic and environmental monitoring equipment can be shared among a number of systems.

2.5.1 Basic Mobile RF Heating System - This system was designed, developed and integrated by KAI Technologies Inc. of Woburn, MA and its Western Field Office in Provo, UT. The principal components, as shown in Figure 1 are:

Instrument Shelter:	8 ft. x 8 ft. x 20 ft. insulated steel utility shelter with HVAC and AC power distribution. The unit features an air-shock isolation rack configured to protect the 25 kW RF generator cabinet and an instrumentation and control rack. The shelter also has a filtered air system to cool the RF generator. The shelter was manufactured to KAI specifications by ICM of Salt Lake City UT.
Trailer:	A 28-ft. flat bed trailer with neck mounted deck and steel shelter is used to transport the shelter. The trailer includes a heat exchanger tank and cooling fluid circulation system for dummy load testing of the RF generator. The under deck area also contains four 28 ft. applicator storage bays. A typically loaded trailer weighs 20,000 lbs. The basic trailer is a Hillsboro model 200, Hillsboro, KA. The storage areas and modifications were constructed to KAI specifications by ICM of Salt Lake City UT.
Truck:	A heavy-duty pickup truck modified for operation with the trailer as a 30,000 lb. GCVW combination vehicle mobilizes the system. The truck frame also carries a rack system suitable for transport of applicator assemblies of up to 30 ft. in length and emplacement tower sections. The truck is used for general site support tasks during a heating program. The truck is a Chevrolet Sierra model 3500.

2.5.2 Key system components within the instrument shelter - These components are listed by generic names in the block diagrams of Section 2.1.

AC Power panel:	The shelter is equipped to accept 3-phase 208 to 240 VAC power from a utility or Diesel generator source. The shelter has a 3-phase 200 Ampere power panel (WYE and DELTA feed options). The 3-phase

[6] A phased-array system requires additional phase control equipment and fiber optic communication links between the master system and the slave generating units.

utility feed is spliced to the 0000 guage copper entrance feed lines at a weather head on the corner of the trailer. The lines are metered with two levels of transient and surge/vervoltage protection. The system also has a 1-phase 100 Ampere, 110/220 VAC panel that is powered from a 3-phase WYE service or a seperate 1-phase feed. The 1-phase power distribution system includes a 1 KVA uninteruptable power supply (UPS) to protect critical control and data acquisition functions. The 1-phase panel also controls power for the auxiliary cooling blower of the RF generator as well as for the air conditioning and lighting of the shelter.

RF Generator: RF Power Products model 25,001D generator (built to KAI specifications and with KAI operation and control modifications). Designed for operational compliance under Part 18 of FCC regulations for Industrial, Scientific and Medical (ISM) equipment.

Frequency: 27.12 or 13.56 MHz operation (crystal controlled)
Emission: A0 (CW unmodulated)
Output: 25,000 Watts, tuned output stage (harmonics suppressed)

The output is continuously adjustable from 100 to 25,000 Watts, the maximum power is set by the line voltage of the site 3-phase power service. For this test the maximum available power will be 23,000 Watts.

Details: The generator was operated at 27.12 MHz for this program. The unit is an optimized industrial design with a 3CX15000A7 ceramic vacuum tube output stage and automatic power controls. The modifications include interfaces for remote control and function monitoring.

Matching Network: (Tuner) KAI custom design with proprietary features.
Frequency: design centers of 13.56 MHz and 27.12 MHz for specified impedance transformations.
Power: > 25,000 Watts
Details: "T" network design with input and output ports using fully shielded 1-5/8" EIA connections to rigid line coax. The unit contains motorized input, shunt and output controls and interfaces to a KAI control and tuning software package.

Dummy load Coaxial Devices model 6025, 25 kW, water cooled resistive load.

CPL #1: 25 kW dual port directional coupler, 2 to 30 MHz, 70 dB coupling,

	Werlatone model C2892.	
CPL #2:	25 kW dual port directional coupler, 2 to 30 MHz, 70 dB coupling, Werlatone model C2892.	
CPL #3:	1.5 kW dual port directional coupler, 1.5 to 35 MHz, 30 dB coupling. Bird model 4266.	
RF Switch #1	25 kW transfer switch, Delta model 5730E	
RF Switch #2	25 kW pressurized transfer switch, Dielectric model A 50000-203.	
Controller:	This is function is developed by the integration of a number of commercial components.	
	Computer:	Industrial Computer Source rack mounted system with 80386 and 80387 processors, 8 MB RAM, 240 MB hard disk with GPIB and modem interfaces.
	Software:	DOS 6.2 operating system running TBASIC V1.9 by Transera, Inc. of Provo UT. The data acquisition is a customized and proprietary package of capabilities developed from the Eyring Broadband Antenna Test System (BATS) software. The program was done by the Communications Systems Division of Eyring Corp. of Provo, UT and KAI Technologies. The remote control software for the system is Carbon Copy Plus.
	Switching:	HP 3488A switch controller with five interface modules to provide contact closures, coaxial switching and TTL sensing/logic interfaces. The unit is interfaced to the RF generator, tuner and RF switches and well as system annunciators and safety monitors.
	Comm.	Communications with the system is via a high speed error correcting FAX/modem suitable for wireline or cellular communications. The unit is capable of sending a data message to a host computer, a digital display radio pager or a FAX machine. The system also communicates via a UHF radio data voice message link to signal the operators hand held radio or scanner of a system status message.
Diagnostics:	This function is again provided by a number of commercial	

components. The items listed here are acquire data that is logged by the control computer in a data acquisition mode. Software setup files define if a channel is to be used for control processing for limit alarms warning or control actions.

Sensing:	Two HP 3457A scanning digital multimeters (DMM) with 22 channels are used to monitor system voltages, temperatures, pressures, and power levels
Temperature:	Luxtron 790 floroptic thermometer using fiber optically coupled sensor probes to monitor the Heating Zone.
AC Power:	Ohio Semitronics PC5 and MVT 3-phase Wattmeter tand Voltage transducers interfaced to the HP3457A DMM
Vector Voltmeter:	HP 8508A with frequency coverage from 0.1 to 2000 MHz with a phase locked sensing channel sensitivity of down to 10 uV (-87 dBm)
Signal Generator:	HP 8656B with coverage from 0.1 to 990 MHz and output levels of up to+13 dBm.
Network Analyzer:	HP 3577B network analyzer with 0.1 to 200 MHz coverage with an HP 35677A S-parameter test set.
TDR:	Tektronix 1503C time domain reflectometer
Megger:	Biddle model 218650CL with 500 to 5,000 VDC test voltages.

Environmental monitors: These items are used measure site condition, above and below ground. The isotropic probe is used to monitor site safety conditions for USAF ad OSHA compliance. The spectrum analyzer is used to measure RF harmonica emissions for FCC compliance.

Spectrum Analyzer:	HP 8591E analyzer with EMC personality modules.
Biconical antenna:	EMCO 3104A calibrated antenna and insulated

	tripod. 20 to 200 MHz calibration.
Isotropic probe:	Holiday model HI-3012 with MSE and HCH probes. A foam spacer ball for 0.1 m near contact measurements (FCC defined specification).
Thermocouple readout/calibrator:	Omega CL 23 type T digital readout used for all on site temperature measurements of thermocouples.
Weather:	Davis Instrument Weather station II with dewpoint and rainfall sensors.
IR Probe:	Omega model OS36-T-240 passive IR thermocouple unit with type T output mounted on a PVE extension probe.

2.5.3 Key system components outside of the shelter - These components are listed in the diagrams of Section 2.1. The use of these components varies greatly with the site configuration. The transmission line and switching components are commercially available for AM/FM/TV broadcast applications.

Transmission lines: 1-5/8" rigid copper coaxial lines were used throughout system for system interconnections and to transfer power to the heating antennas. The transmission lines were pressurized with 15 PSI nitrogen and delivered power to either heating antenna through a computer controlled, motorized RF switch. Delivery of power to the antenna was typically >98% efficient for these components. Typical units were manufactured by the Andrew Corp. as type 561 transmission lines.

RF Switch #3: Dielectric model A 50000-203, pressurized, heated, 1-5/8" EIA flange connections. The switch is housed in a weatherprof, secure housing with adjustable legs and universal joints on each of the ports connections.

Applicators: Two KAI 3.5" antenna assemblies designed for subsurface RF heating applications. Drawing set KAI--0690-30.

Frequency:	design centers of 13.56, 27.12 or 40.68 MHz can be configured.
Power:	25,000 Watts
Diameter:	3.5" OD w/o centralizing spacers
Length:	7.38' to 11.38' span set for soil conditions (27.12 MHz)
Feedline:	1-5/8" EIA flange

Details: The antennas are adjustable length, dipole-type, end-feed structures with 1-5/8 in. EIA feedlines. The standard design employs aluminum radiating elements with Teflon insulating components. The use of Teflon limits its to operation to an ambient temperature of 200 degrees C (392 deg. F). Operation can be extended above this temperature by the use of ceramic insulating components and localized cooling of the applicator assembly

Guide tubes: (Sleeves) The applicators were vertically emplaced in a vertical boreholes lined with 4.33 in. ID high temperature fiberglass liners. The liner wall thickness was nominally 0.25 in. The outside diameter was nominally 5 in.

Ground planes: The antenna counterpoise/ground plane at the soil surface consists a 8 ft. by 22 ft. x 0.062 in. expanded aluminum mat pattern mat, extended around and between the 3 ft. x 3 ft. x 0.25 ft. thick aluminum ground plane base plates are located around each borehole sleeve liner. An 18 ft. diameter pattern of twelve aluminum radials of #2 insulated aluminum cable extend from each base plate. The perimeter cables are terminated to form an 18' diameter aluminum radial pattern of #2 Aluminum cable terminated by 5/8 in OD x 4 ft. copper-clad steel ground rods driven about 45 inches into the soil. The radials are centrally capped by an aluminum screen mat that is bonded to the radials. The antenna transmission lines and supporting structures are bonded to the ground plane at multiple points.

Towers: The emplacement towers are mounted to the 3 ft. x 3 ft. aluminum base plates. The towers are constructed from 10' lengths of aluminum antenna mast sections. The masts are jointed to form 10 ft., 20 ft. or 30 ft. emplacement towers. The towers are supported with four aluminum extension tubes with anchored base pads suitable to make the towers self supporting without the use of guy lines. The complete tower includes a 1,500 lb. winch and two rope pulley lines. The towers were built from commercial aluminum antenna mast sections and were fabricated under KAI direction.

3.0 SITE DATA ACQUISITION

Data acquisition at the Kelly site was performed by both Brown and Root and KAI site personnel. The Brown and Root data typically consisted of 40 data point that were acquired manually, one to two times per day. The data points addressed the soil vapor extraction system, site environmental data and three spot measurements from the KAI RF heating system.

For this report, representative items from the following list are presented along with selected, same scale plotting of several items from the Brown and Root data logging of the KAI data and site temperatures and pressures. The majority of the information was acquired to assist in failure analysis or anomaly investigation. Summary records and example data are provided in Appendices A through I.

The KAI data set consists of the following:

3.1 Computer logged data sets - 23 channels of measurements were continuously logged at approx. 20 second intervals and stored every hour during the heating periods. A limited number of temperature channels were logged during the cool down period. The channels, which included real time fiber optic temperature measurements and RF system measurements are defined in detail in Appendix A. The data is logged into individual raw data files and is summarized by a data acquisition file that records that date/time of all system status messages and notes made during the acquisition cycles. The log includes all program directed connections to the cellular phone and the UHF data link to announce status messages and alarms.

The data set acquired by computer logging is described by channel in Appendix A - Site data logging. RF and AC power data is used for the Heating Summary statistics of Appendix B, the power measurement plots of Appendix C and the fiber optic temperature plots of Appendix D.

3.2 IR probe temperature scans of boreholes F1 through F5 - 17 manually acquired temperature measurements at 1-ft intervals from 0.5 ft. to 16.5 ft below the surface. The measurements were made when the applicators were removed from the boreholes for examination. The passive IR thermocouple probe was an Omega model OS36-T-240 unit with a CL23 thermometer that is designed to operate with a wide range temperature accuracy of +/- 5% of a 60 F to 310 F range. This suggests a +/-3 to +/-15 tolerance for the raw measurements (in degrees F). The measured values are also offset by the cable loss and a potential offset for the sensor.

This measurement was used to understand the thermal profile of the heated zone. The fiberglass monitoring wells provided a thermal window into the heated soil through a 1/8" wall of fiberglass and a one to three inch path of packed sand. The temperature profiles that were measured were always lower in temperature than that of the soil since the fiberglass

wall was heated by an air flow. When the air flow past the tube walls was high the temperature differential between the inside well wall and the heated soil could be quite large since the air passing by included a large portion of cooler air mixed with the air in the heated region. When the air flow is low or hot liquids surround the well the temperature difference is small.

The IR probe data sets for the applicators are presented in profile form in Appendix F.

3.3 IR probe temperature scans of applicator boreholes A1 and A2 - 17 manually acquired temperature measurements acquired at 1-foot intervals from 0.8 ft above the soil surface to 15.2 ft. below the surface. The measurements were typically recorded each time the applicator was removed from the liner. *Note: The interior of the liner was continuously cooled with a 400 SCFH air flow that was used to maintain the inside liner wall below the critical thermal damage temperature of 300 deg F (148.9 C). The applicator was also surrounded by a sand pack (several inch path to the contaminated soil) and exposed to the SVE air flow. The temperatures measured inside were always lower than the ambient surrounding soil temperatures.*

The IR probe data sets are presented in time line and profile form in Appendix F.

3.4 Thermocouple temperature profile strings - Two, 19 sensor strings (TC-1, TC-2) and one 7 sensor string (TC-3) were located 5 ft., 6 ft. and 12 ft. from applicator sleeve A2 (applicator #1) at depths ranging from 2 ft. to 20 ft. below the surface. The type T sensors were manually scanned with a thermally stable rotary switch and measured with a handheld digital thermocouple calibrator/thermometer (Omega model CL23). The temperature measurements made with the thermocouples were also lower in temperature than the surrounding soil due to air flow about the sensors that were packed in sand.

The Thermocouple probe data sets are presented in temperature versus time line and temperature versus depth profile form in Appendix E.

3.5 RF System Matching Measurements - Measurements were made periodically of the transmission and reflection "S-parameters" of Applicator #1 and Applicator #2 before, during and after the heating cycle of each applicator. The S-parameters were displayed as Return loss, voltage standing wave ratio (VSWR), impedance and insertion loss between the applicators. The measurements were made with an HP 3577A/35677A network analyzer/s-parameter test system with computer controlled data acquisition by the HAQR program.

Representative measurements are provided in Appendix G. All measurements are listed in the general logging file HAQR.LOG.

3.6 RF System Emissions Measurements - Measurements were made at 3 meters, 10 meters and 300 meters at several locations about the heating site. Harmonic emission measurements (1st at 54.3 MHz through the 6th at 189.9 MHz) were made with an HP 8591E EMC

calibrated spectrum analyzer and an EMCO 3104C calibrated biconical antenna to determine the absolute emission levels from the site in compliance with FCC part 18.305(b). Fundamental frequency emission levels at 27.12 MHz ISM heating frequency were measured in compliance with USAF requests.

A complete set of measurements is included in Appendix H.

3.7 Electric and Magnetic Field Measurements - Periodic measurements were made of the surface fields with a Holiday model HI-3012, portable isotropic field probe. The E-field level was checked daily at the perimeter of the heating zone and logged periodically at three distances from the active heating applicator. These distances were 3 meters, 1 meter, and 0.1 meter (near contact) from the applicator axis at a 1 meter height. Measurement were also mapped several times above the heating zone in detail in terms of E and H fields. The isotropic field measurement was also supplemented at times by an automated measurement of a vertically polarized tuned whip antenna located on the roof of the shelter to monitor ambient field emissions of the heating system at 27.12 MHz.

Representative measurements are included in Appendix H.

3.8 Time Domain Reflectometer Measurements - A Tektronix 1502C time domain reflectometer was used to characterize the transmission lines leading form the line access switch (SW#2) in the RF heating shelter to the applicator selection RF switch (SW#3) and on to each applicator. The instrument produced high resolution charts of the transmission line reflections versus distance that allowed system integrity to be verified and any line degradation to be monitored and located.

3.9 Megger Measurements - A high voltage (5 kV) megohmmeter was used to verify the insulation integrity of the RF transmission line and the applicators.

3.10 Magnetic Field Probe Measurements - Low level magnetic field probe measurements were made at well F2 as part of the tuning measurements of Applicator #1. The Applicator was driven by a low power signal generator. The field was received with a pre-amplified magnetic probe that was connected with a ferrite isolated transmission line to a battery powered spectrum analyzer (HP 8591E) on the surface. These measurements were not made at high power or after the boreholes were to hot to safely insert the magnetic probe without damage.

3.11 Applicator air flow and transmission line pressurization/flow and nitrogen tank pressure - Air flow was directed to cool the applicator within the fiberglass sleeve and was controlled to protect the liner from overheating. The transmission lines were filled with nitrogen and in the event of a leaking seal were maintained at a controlled flow rate. The nitrogen tank pressure indicated the remaining quantity of the stored gas.

3.12 Weather data station data - This data was logged automatically for the last half of the

program. The measurements included outside temperature, humidity, barometric pressure, and rain.

3.13 Photographic records - The program was liberally photographed to document the setup, heating cycles, cool down and dismantling of the site. The data set was recorded on 135 mm print film with wide angle-, normal- and macro- lens photographs.

3.14 Communications program access log - This file records all communications to and from the control computer over the modem/cellular phone link.

3.15 AC power consumption - The KAI instrument shelter is supplied power through a 3-phase 208 to 230 VAC DELTA or WYE service entrance. The 120/220 VAC single phase requirements of the system can be derived from a WYE feed or from a separate service entrance. Both service entrances are metered with Watthour meters for all external power. However, when 120/220 VAC is drawn from the WYE feed internally it is not routed through the 1-phase service metering panel.

Start and finish numbers and some spot numbers were recorded for each meter. However, several changes from a single 3-phase feed to a dual feed and back during the program made this data very difficult to interpret. The data set also includes various configurations of outdoor site lighting as well as heavy air conditioning power usage.

The 3-phase AC power consumption log for the RF generator that is logged by the computer is a better time line on AC power usage. From this log the typical 24 overhead load can be added to approximate the system's power usage.

END FILE: KELLY3.A

4.0 PROBLEMS ENCOUNTERED AND LESSONS LEARNED

During the course of the program a number of technical problems were encountered that visibly influenced the data set and modified the course of some test activities. This section covers the period from 28 March (arrival on site) through 13 June (completed packing of Rig#1). None of the problems encountered were outside of the range of reasonable engineering solutions and most were solved quickly on site with minimal impact to the program.

4.1 System configuration - The items listed here are ones that specifically interacted with site's operation.

4.1.1 PROBLEM: The fiberglass well liner was considered at risk for delamination if the temperature exceeded 300 degs F. When the RF generator was set to turn off and allow cooling of the well liner, the average heating rate per hour being applied to the formation was relatively low.

> SOLUTION: Teflon tubes were attached to the outside of the applicator to flood the bottom of the liner with cool, filtered compressed air. A flow rate of 800 SCFH was used to maintain cooling of the liners. The typical flow was 400 SCFH to each liner.
>
> Note that ideally the RF generator was to switch to the other applicator as the first unit cooled down. However, the RF generator restart and control problem did not allow this mode of operation to be undertaken reliably. See section 4.3.1

4.1.2 PROBLEM: The majority of the SVE extraction wells may not have been ideally screened for extraction from the Heating Zone located in the upper half of the Treatment Zone. A large percentage of the screened wells drew air from unheated soil regions. The mixing of the cooler air with the heated air in the path to the extraction wells may have condensed some VOCs and SVOCs.

> SOLUTION A: The bottom of the Treatment Zone could have been heated first for extraction. The heating of this region should significantly enhance soil permeability in this region. Then the applicator could have been incrementally raised to heat the top half of the treatment region. This approach treats a greater volume and provides vapors with either a short path to the extraction well or a pre-heated permeable path to the extraction well.
>
> SOLUTION B: The well could be made with two concentric tubes. the outer tube would be fully screened. The inner tube could be screened to match the applicators's heating span. The inner tube would be adjusted within the well to mach the position of the applicator.

4.2 Data acquisition and measurements

4.2.1 PROBLEM: The fiber optic temperature probes demonstrated wide temperature fluctuations at or near 100 degrees C.

> SOLUTIONS: Place shroud over tip (factory recommendation), and use shorter lengths of high loss probe cables. The repolishing and testing of all optical extension cables was also recommended.
>
> EFFECT ON PROGRAM: The temperature fluctuations appeared to be due to water vapor being collected in the Teflon tube used to protect the fiber optic probe. After this water was driven out the system stabilized. The most difficult aspect of the problem was in estimating with certainty the temperature the well liner during this periods. This problem did not contribute to any operating problems.

4.2.2 PROBLEM: Some channels of the fiber optic temperature measurement system stopped operation when the probe temperature dropped below about 40 degrees C.

> SOLUTIONS: The three splices in the fiber cable were not ideally matched for lowest possible loss. Ideally each probe would be a short run to a single extension cable of <250 ft. that runs directly to the instrument.
>
> EFFECT ON PROGRAM: None since the most critical probes, channels 21 and 22 did function without this problem.

4.2.3 PROBLEM: Most of the 0.25 in. OD Teflon tubes planned for the emplacement of fiber optic probes and thermocouple scanning probes were crushed by the setting of the bentonite clay seal used to cap the site. The only usable tubes were attached to the walls of A1 and A2.

> SOLUTION: The IR temperature measurement system became the primary means of characterizing soil temperatures within the heated zone. In the future a thicker wall (higher cost) Teflon tube could be used protect the fiber optic and thermocouple leads.
>
> EFFECT ON PROGRAM: The loss of the Teflon tubes limited the number of temperature points that could be acquired for the program. The temperature measurements made with the IR probe were taken through the wall of a larger tube with significant air flow through its surrounding sand pack. Therefore the temperature measurements available to the program were from fewer points, with measurements that were generally indicating values lower than the actual soil temperatures due to SVE flow action. The channel 21 probe outside well liner A2 was blocked (crushed) and could move much lower than the 10.5 ft. position it was set at. This was a small but contributed point to the decision to position Applicator #1 at a center of 9.5 ft.

4.2.4 PROBLEM: Low temperature readings of IR and TC measurements

SOLUTION A: Monitor air flow underground with a hot-wire annometer type probe to develop a correction temperature for some locations. The cooling effect of the air flow may be used as an indicator to determine if a temperature probe is in a dead air or convective flow environment.

SOLUTION B: During the full power heating program, confine some native soil target material in a sealed container with a fiber optic probe to determine the isolated, in-situ heating rate of the soil sample within the RF heating zone. These sensors would also be used near open temperature monitoring points in the RF zone.

EFFECT ON PROGRAM: The low reading trend appears makes it more difficult to estimate the actual soil temperatures developed in the heating zone.

4.2.5 PROBLEM: The fiber optic thermometer software interface randomly dropped temperature values to a value of 1,2,3 or 4 corresponding to the channel number of the measurement probe. The effect was timing related and did not appear at previously tested sampling rates.

SOLUTION: The problem was recognized within the first few days of the data logging operation and was solved with a field programming change.

EFFECT ON PROGRAM: The recorded data shows a high density of "spikes" displaying temperature drop outs that were not real. The drop outs did cause a problem with the control system. The "drops" were recorded as 1,2,3, or 4 "degrees" by the data acquisition/control system. These low "temperatures" caused the computer to restart the RF generator before the cool down restart temperature was met.

By itself, this problem was manageable as an operational annoyance until the software was changed. However, in the context of a power line source instability at the site the computer requested RF power restarts were not reliable and often left the generator in the RF OFF position if not noted by a site observer.

4.3 Operational items - Prior to this program the generator was modified to operate at both 13.56 MHz and 27.12 MHz. The generator was run with this modification by a Diesel generator driven system for several hundred hours. The system was also upgraded to operate with a new fiber optic thermometer that had received limited testing.

4.3.1 PROBLEM: The RF generator would not restart reliably under computer control.

SOLUTION: The problem was isolated through a number of detailed troubleshooting steps. Initially it was thought that the RF Generator was the source of the problem. Later it became clear that the source impedance of the 3-phase power line was too

high for the load drawn by the generator when it switched from RF OFF to RF ON. The 3-phase, 0 gauge aluminum cable[7] was replaced with 00 gauge copper cable to solve the problem.

DISCUSSION: Initially it was speculated that the problem was due to a generator instability associated with the recent modifications to operate at 27.12 MHz or 13.56 MHz. Careful troubleshooting indicated that the conversion did not cause a problem but that the 3-phase utility power was exceptionally unstable. The problem was identified to be due to several high resistance, (copper/aluminum) dry splices in the 3-phase power feed and the use of an undersized, 0 gauge, aluminum feed cable to connect the instrument shelter to the power transformer. It was found[8] that the RF generator's power control system was very sensitive to the utility line impedance when it automatically reconfigured its main power transformer from a "WYE" to a "DELTA" feed as the RF ON state was initiated by. This switching process was timed by an adjustable time-delay relay that sometimes could be adjusted to lower the probability of the RF generator not going to the ON state. However the problem remained intermittent but occurred less frequently and appeared linked to the daily variations in the utility voltages.

EFFECT ON PROGRAM: During the first several weeks of the program this problem required round-the-clock monitoring of the system by KAI personnel. The average RF power level was lower than optimum. After the splices and power feed cables were replaced the system reliability improved dramatically and the system worked smoothly under computer control.

4.3.2 PROBLEM: The 25 kW RF generator randomly tripped OFF. This was indicated with an intermediate power amplifier (IPA) annunciator light, an Overload Trip light and a system program alarm.

SOLUTION: The problem was minimized first by careful tuning and then with operation at below maximum RF power level setting. Later it was observed that the problem was related to both high power operation and the daily cycle of the 3-phase power line voltage and the available line voltage. The problem was isolated by correlating the IPA trips to transients riding on rising power line voltage levels (similar transients at lower voltages did not produce the trip).

---

[7] This cable was previously used for the service trailer of a previous program. It was originally thought to be the 00 gauge AL cable that program used at 3-phase, 480 VAC.

[8] Prior to this program the RF generator was used with a number of utility and diesel generator power sources with hundred of hours of operation with each source. The RF generator field support staff indicated that this problem had not been encountered within the 10 years this product has been installed at industrial sites.

The short term solution was to retune the RF generator output stage to optimally match the power line voltage to output maximum RF. This meant temporarily setting the power output lower before the voltage trend increased for the day and then retuning it an hour or more later when the voltage stabilized at a higher value (e.g. end of main work day at Kelly AFB). This problem was also improved with the power line splices were replaced and the line replaced.

The long term solution has involved isolating the RF generator power supplys for the low voltage, bias and control voltages from the voltage swings of the 3-phase line. The upgrade has been implemented since the Kelly tests by adding an uninteruptable power supply (UPS) to the system with an interface to these RF generator circuits. This modification stabilizes the low level RF drives to the IPA stage of the generator.

EFFECT ON PROGRAM: The IPA trips required closer monitoring of the RF generator's adjustments when it was set for maximum power output after the power line was repaired. Trips did send immediate alarms to the operators and seldom accounted for more than 5 minutes of down time. Trips could be avoided by planning the tuning of the generator around the anticipated line voltage trend for the day or setting the generator approximately 1 kW below its maximum power setting.

4.3.3 PROBLEM: Applicator #2 in well A1 failed after 8.15 days of operation. The applicator initially indicated a slow nitrogen leak.

SOLUTION: The problem was based on a slow loss of the nitrogen pressurization that protects the feedline from high voltage breakdown. The line ultimately failed after we ran out of nitrogen during the Memorial Day holiday. A larger supply of nitrogen could have maintained the unit in operation until the leak could have been fixed. The damage to the applicator was repairable.

EFFECT ON PROGRAM: The power was switched back to Applicator #1 while Applicator #2 was removed and cooled. The unit was to be immediately repaired in the field by replacing the heat-distorted copper center conductor. However, it was discovered that the replacement conductor was damaged in transit. The factory supplied a repair part by an overnight package service to repair the damaged spare conductor. It was determined that the conductor could be repaired with the part and the use of a speciality welding companies services for the required high temperature copper-to-copper welding. The high temperature repair was placed on hold due to the uncertainty of the program's extension schedule. Therefore a simple mechanical repair was effected to the center conductor and Applicator #2 was placed back in low power service about one day after it was removed. The heating of Applicator #1 continued for 12.7 days till the heating period ended.

END FILE: KELLY4.A

5.0 DATA ANALYSIS

This analysis section provides samples of the data records gathered during the program. The focus is on the start and stop points of the heating cycles of applicator #1 and applicator #2.

5.1 Power delivery- The power delivery of the RF heating system is dependent on three components. The AC power input, the RF power generator, and the RF power delivery. Details of the power generation and delivery are provided in Appendices B, C and I.

5.1.1 AC power input - The system was powered by a 3-phase, WYE utility feed for the RF generator and instrument shelter. The AC voltage measured at the RF generator test points had the following characteristics:

- Nominal 3-phase line voltages were _____ **(left out for draft to review statistics)**

- The typical max to min swing for the base was _______ before the splice repair and cable change and _____ after the change.

- The estimated AC input power used for the RF generator was estimated at 26,693 KWH which was back figured from generation with a 65% conversion efficiency. It is likely that the low operating efficiency periods of the program increased this amount.

- The estimated AC power used by the site was greater than 36,053 KWH. This number assumes that the system was operating at high efficiency and was developed by back figuring against the amount of RF that was generated and a 5 kW/hr overhead rate..

5.1.2 RF Power generation - The RF power generated for the program is summarized as follows:

Applicator #1	11,201 KiloWatt hours over a 41.77 day span
Applicator #2	4,248 KiloWatt hours over an 8.15 day span
	15,549 KiloWatt hours over a 49.92 day span

The overall RF generation rate for the entire span was 12.97 KiloWatts/hr. This figure should have been in excess of 19 KiloWatts/hr. This would have increased the RF generation by the system to over 22,763 KiloWatt hours.

Additional calculations, alternate estimates and detailed tabulations are provided in Appendix B. A summary plot of the RF power trend over a day 7 to day 77 span is in Appendix I.

The RF power is generated by an industrial grade power oscillator based on vacuum tube technology. When the RF generator is optimally tuned the unit transforms 3-phase AC power

to RF at 27.12 MHz with a conversion efficiency of approximately 65%. This is commonly called "cabinet efficiency" since it includes not only the efficiency of the final RF output stage[9] but the power consumed for the earlier driver stages and the systems internal cooling blowers.

The total efficiency of the power generation system involves the following typical components:

25 kW RF generator with cabinet efficiency of 65%:	38,460. Watts
External ventilation system energy requirements:	350. Watts
Control and monitoring instrumentation:	650. Watts
Instrument shelter HVAC and lighting (average):	2,500. Watts
	41,960.00

Based on a 25 kW RF output this example has a calculated efficiency of 59.5% for total system efficiency for controlled RF generation.

The RF generated for this program was often at less than this 59.5% value due to limitations in the stability of the AC utility power supplied to the instrument trailer. The non-optimum power conditions required that the RF generator be tuned for stability under these varying conditions.

5.1.3 RF Power delivery - The RF power generated is connected to a high efficiency, remote controlled "T" matching network (tuner). The output of the network is coupled to the applicators with low loss switching and rigid transmission line paths. Typical transmission efficiencies for this path is excess of 98% when the applicator is pre-matched the soil. In the case of this program the transfer from the generator to the network to the applicator was nearly ideal.

- 11,201 KWH was delivered to Applicator #1 in well A2
- 4,348 KWH was delivered to Applicator #2 in well A1
- 15,549 KWH delivered to the heating zone.

Details are provided in Appendix B.

[9] The tube output stage alone can exceed an efficiency of 80%. Values such as this are often mistakenly used as the efficiency of the entire device that uses the tube without accounting for the overhead of support circuitry and cooling. This is also true of many semiconductor devices.

5.2 Temperature measurements - Details of the temperature measurements are provided in appendices D, E, F and I. In general, the fiber optic measurements were the most stable measurements but there positioning was limited. Most readings presented here should be considered lower than actual due to the uncertainty of the air flow and mixing of air in the vicinity of the sensors.

5.2.1 Fiber optic temperature probe - Channels 21 and 22 were the primary channels of interest. Channels 23 and 24 were largely used for well liner protection. On occasion Channel 23 was used for monitoring in monitor well F3 but little was seen due to the cooling trends of the SVE flows. Detailed samples of the data sets are contained in appendix D

- The plots showed a period where the sensor temperature was held at just below 100 degs. C while water vapor was removed.

- The fiber optic probes were used to control the temperature below 150 degs C. at the liner walls. The temperature beyond the walls was always higher in temperature than the wall. The RF energy developed heat in the region outside of the liner. The applicator and the liner themselves produced very insignificant amounts of heat from the RF energy passage through them.

- The maximum temperature recorded was 233.9 deg. C on 19 May during the heating of Applicator #1. This temperature built over six hours from 165 degrees and than dropped slowly as the energy was removed from Applicator #1 and Applicator #2 was started. The heating was stopped due to excessive temperatures on the fiberglass well liner. The temperature appeared to be due to a flow of material in the heating zone that moved into the sensor region since it did not occur within the first 100 hours of the heating cycle when susceptible materials (e.g. water and hydrocarbons) close to the liner should have heated most strongly. A plot if this event is in Appendix D.

- Maximum recorded temperatures were:

Ch 21, well liner A2	>233 deg C.
Ch 22, well liner A1	>150 deg C.

5.2.2 Infrared probe thermal scans - A complete set of scans are contained on Appendix F. The following observations can be derived from the data set.

DRAFT NOTE: additional statistics and profile summaries are being prepared as a correction to this draft.

- Maximum recorded monitor well temperatures:

F1 near A1 East	>115 deg. C
F2 near A2 East	>95 deg. C
F3 center	>95 deg. C
F4 near A1 West	>112 deg C
F5 near A2 West	>120 deg C

o Temperatures higher on West side of zone - perhaps due to a smaller air flow on this side since this was the side for deep passive injection of ambient air.

o Both A1 (applicator #2 heating cycle showed higher peak temperatures. This appears to be due to the more rapid heating rate used and the delayed configuration of the SVE system.

- The measurements from monitor wells F1, F2 and F3 were most strongly affected by the SVE air flow configuration since they were on the East, extraction side of the system.

- The maximum recorded well liner scan temperatures were:

A1 (approx 1 day after heating stopped)	> 175 deg. C
A2 (29 April)	> 145 deg. C

5.3.3 Thermocouple strings and probes - A complete set of scans are contained in Appendix E. A series of probe measurements for the SVE system (e.g. SVE output temperature) is contained in Appendix I.

- Maximum recorded temperatures

TC-1, East of A2	>82 deg. C
TC-2, South of A2	>62 deg. C
TC-3, South of A2	>39 deg. C

- The bottom measurement (20 ft level) in each well showed an upward trend from approximately 22 deg.C to 32 deg. C over the span of the program

5.3 RF applicator measurements - This is a select sample of a large data set. A key to the figures of this section with a definition of return loss is provided in Appendix G. The plots presented here are provided in larger scaling and with additional supporting plots.

5.3.1 3-D scan of A2 borehole - Borehole A2 was scanned with several test dipoles prior to setting up heating applicator #1. The test dipoles were constructed from the same 3.5 in. OD aluminum extension tube sections that were used to assemble applicator #1. The test dipole differed from Applicator #1 in that its feed line was a 0.5 in. dia. flexible insulated-jacket coaxial line without a connection to the ground plane at the surface.

The test dipole was set at five element spans (74", 78", 82", 86" and 90") to evaluate the subsurface soil characteristics at four reference depths (-5,-10,-15 and -20 ft.). Figure 17 is a return loss plot of the 78 in. dipole for the four sampling depths. From this plot it can be seen that good matches (significant negative values) for this dipole occur at depths of 5, 10 and 15 feet for the 27.12 MHz heating frequency (vertical marker).

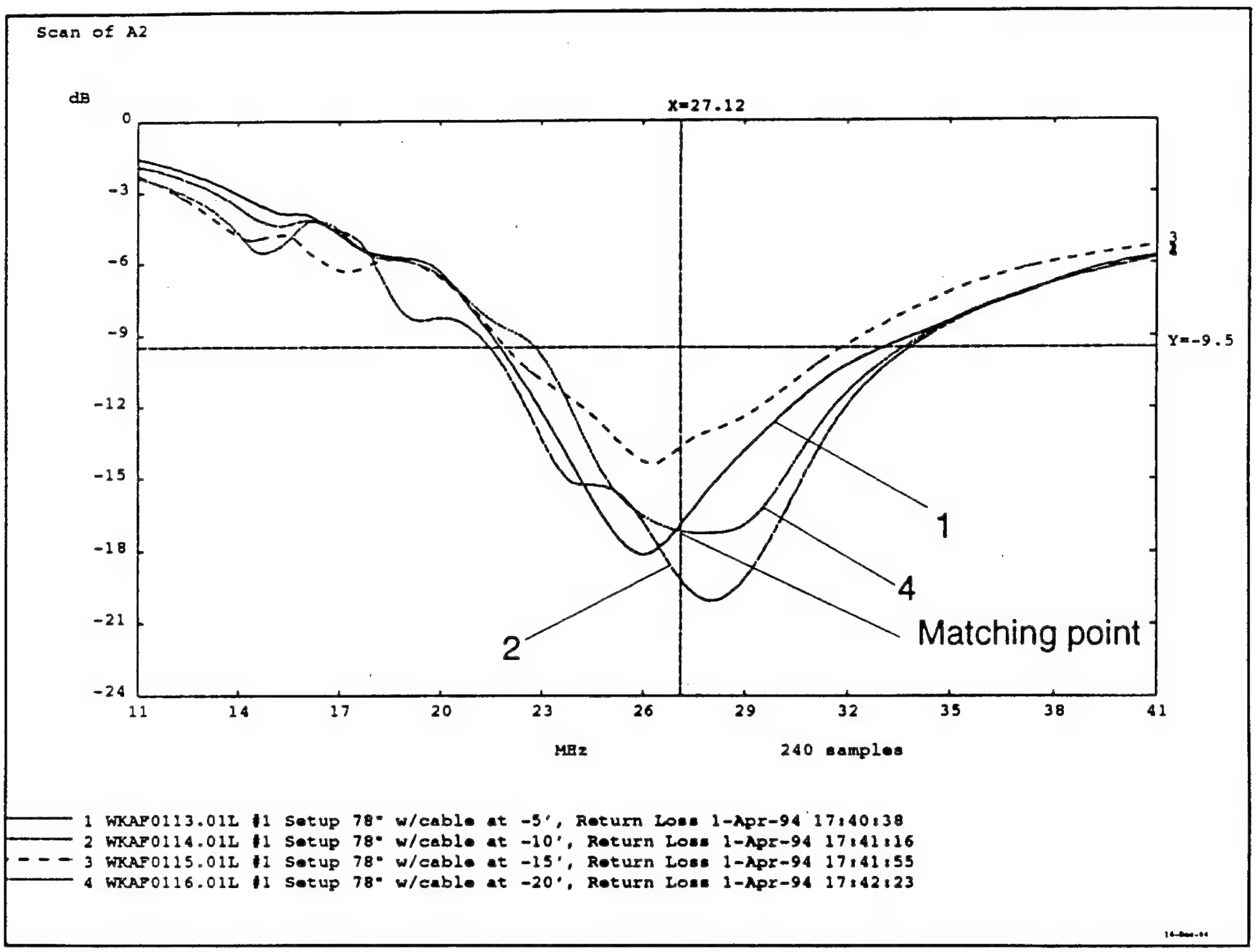

Figure 17 Overlay plot of four test dipole return loss measurements for 5 ft. to 20 ft. center depths in well A2.

This suggests that this region contained a higher density of electromagnetically lossy materials (water and hydrocarbons) than an adjacent region such as at 15 feet. Energy was strongly absorbed from the test dipole at this frequency.

Figure 18 is a 3-D display of this same data. It is important to note that these measurements represent the *average* electrical properties of a 78" vertical span of soil surrounding the well for a penetration distance of perhaps 12" to 48". Therefore the return loss measurement, for a dipole at a 20 ft. depth spans from 16.75 ft. to 23.25 ft. The measured data from these dipole measurements is of a form that can be modeled[10] with the programs NEC-3I and PAT7 to estimate a set of *average ground constants* that can then be used to plan a tuning strategy and model system performance. These average ground constants cannot be directly related to site sample analysis due to the inhomogeneous nature of the soils at the site. A complete set of scans is in Appendix G.

The applicator #1 and #2 setups differed from the test dipoles in that they were connected to the surface with sections of 1-5/8 in. dia. rigid copper transmission lines. The transmission line was radially grounded to the base plate ground plate as it exited the well. The ground plate was then connected to the ground plane screen and a set of radials. This more complex geometry does not allow for a direct translation of the test dipole data but does bracket the expected tuning setting.

The following observations can be made from the scan data:

- The physical inhomogeneity of the contaminated soil is evident in the return loss scans with a test dipole.

- Analysis of the scan data indicated that the applicator could be successfully tuned at all depths of the well.

- The well could be mechanically scanned to apply uniform heat to the entire well.

[10] See section 6.1 on electromagnetic modeling.

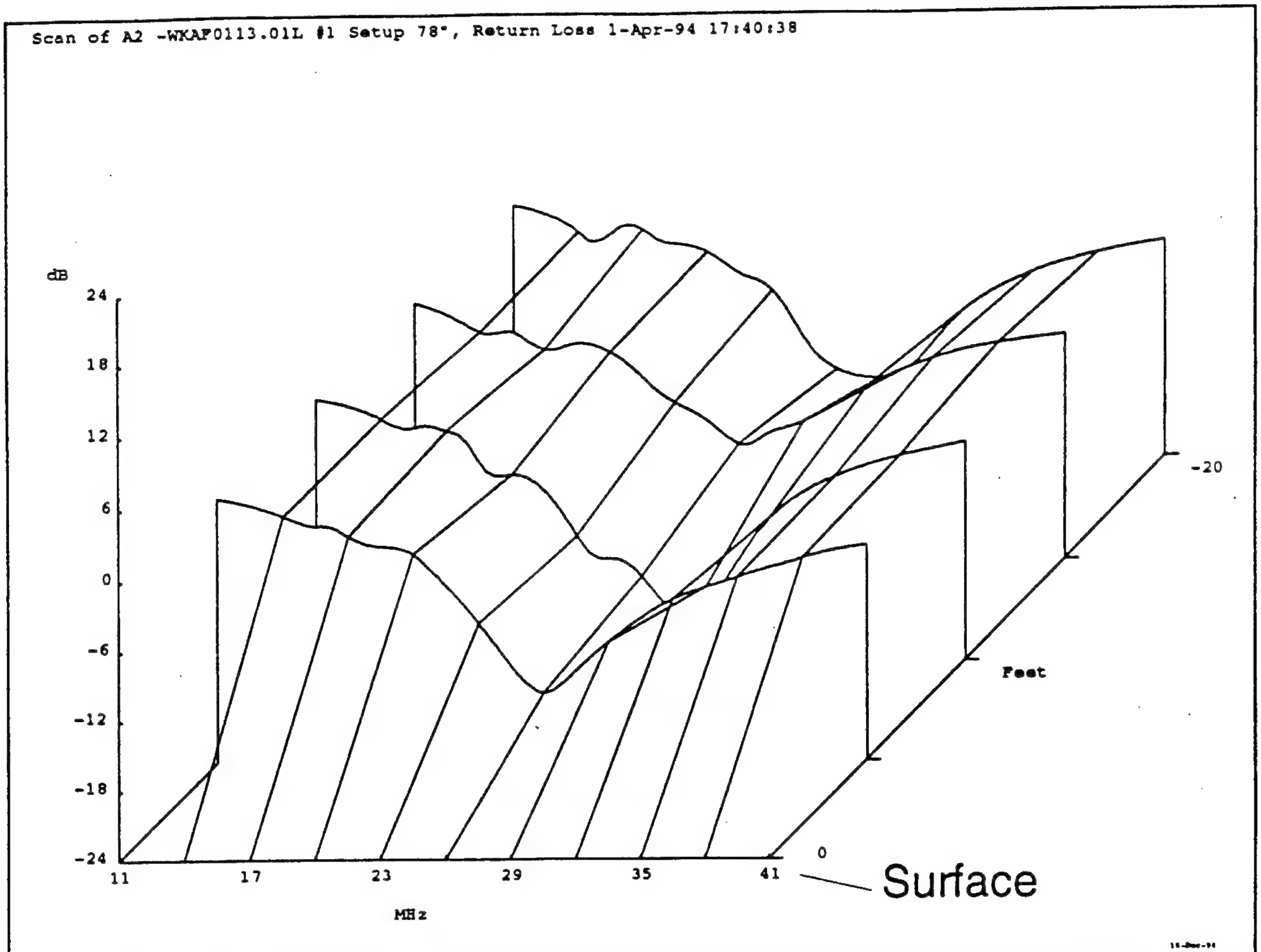

Figure 18 3-D display of dipole return loss versus depth for a scan of well A2.

5.3.2 Pre-heat measurements and applicator system tuning - Figure 19 compares the pre-heating return loss characteristics of Applicator #1 (in well A2) and Applicator #2 (in well A1). The applicator radiating element spans have been set to 100 inches (8.33 ft.). This long element span was selected to allow a 27.12 MHz resonance of the applicator after contaminants and water near to the applicator well liner were removed after several days of heating.

Plot line "1" for Applicator #1 shows a resonance higher in frequency than Applicator #2, plot line "2". The average soil characteristics about applicator #2 appear to be more energy absorbent. Therefore the return loss is larger and its graphic display is "deeper". These measurements were made with the HP 3577A network analyzer with a calibration point set at the center feedpoint of the applicators which is at a depth of 9.5 ft below the ground plane.

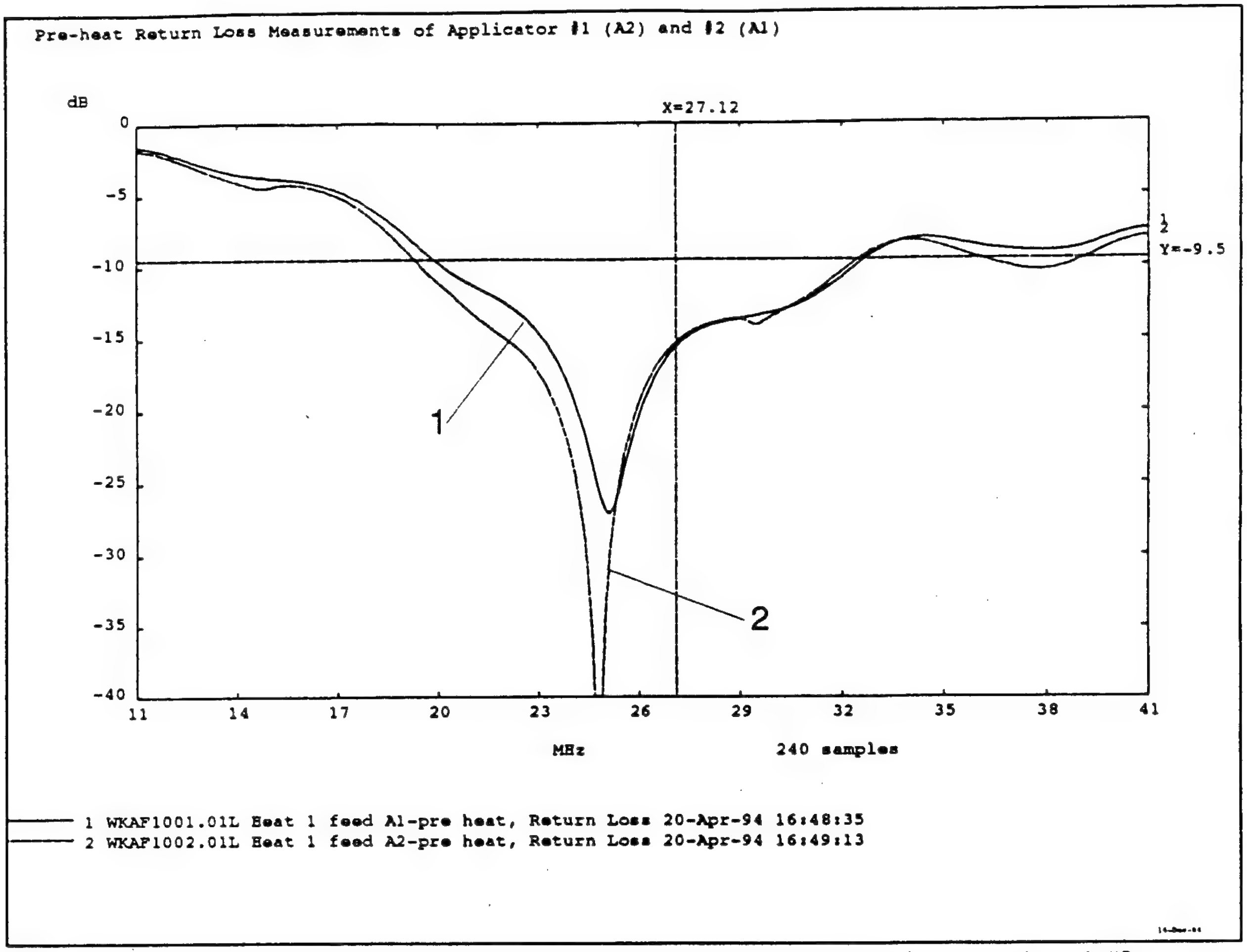

Figure 19 Comparison of pre-heat return loss measurements of Applicators #1 and #2.

Figure 20 is a return loss plot comparison of the applicators when they are matched to the RF generator by the 25 kW tuner. The measurements were calibrated to the test port of RF SW #1 at the input to the tuner. In this plot a common tuner setting was used for both applicators. The tuner matched both applicators to a resonance with a 23 dB return loss at 27.12 MHz.

Measurement applicator and tuned applicator data sets such as Figures 19 and 20 were recorded at the start and finish of each heating cycle. Initially the tuner was set for the compromise match for both applicators. However, when it became apparent, within Heating cycle one, that the energy could not be evenly applied due to the power stability problems, only one applicator was optimally tuned.

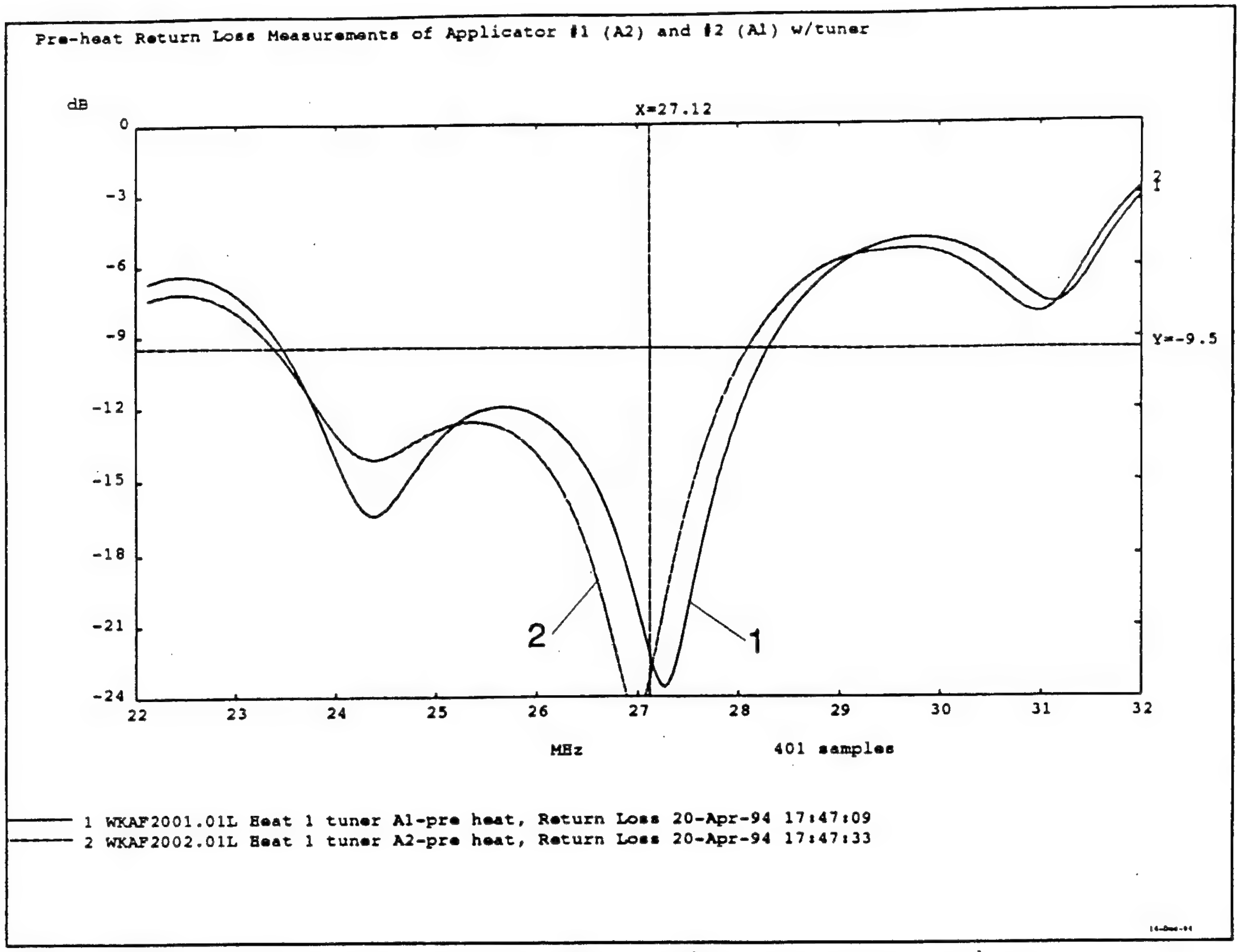

Figure 20 Return loss measurement of applicators with common tuner settings.

The observations that can be made from this data set are:

- The starting match point for the applicators was approximately 2 MHz below resonance.

- The starting match could be tuned with a common tuner setting for both applicators.

5.3.3 Applicator matching trends with heating - The RF heating applicators were initially tuned below the resonance point that was expected later in the heating cycle. Figure 21 compares a preheat baseline return loss measurement for Applicator #1 with two measurements taken within the first heating period[11]. Plot line "2" is near resonance at 27.12

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[11] Applicator #1 is labeled A1 in the plots and Applicator #2 is A2. At the time of these tests Applicator #1 was also in the well labeled A1. This was in error with site

MHz on 3 May. On 20 May the resonance has shifted to approximately 29 MHz. At this point the soil outside of the applicator was over 230 degrees C. and the applicator was turned off. Applicator #1 remained off until 30 May when it was restarted.

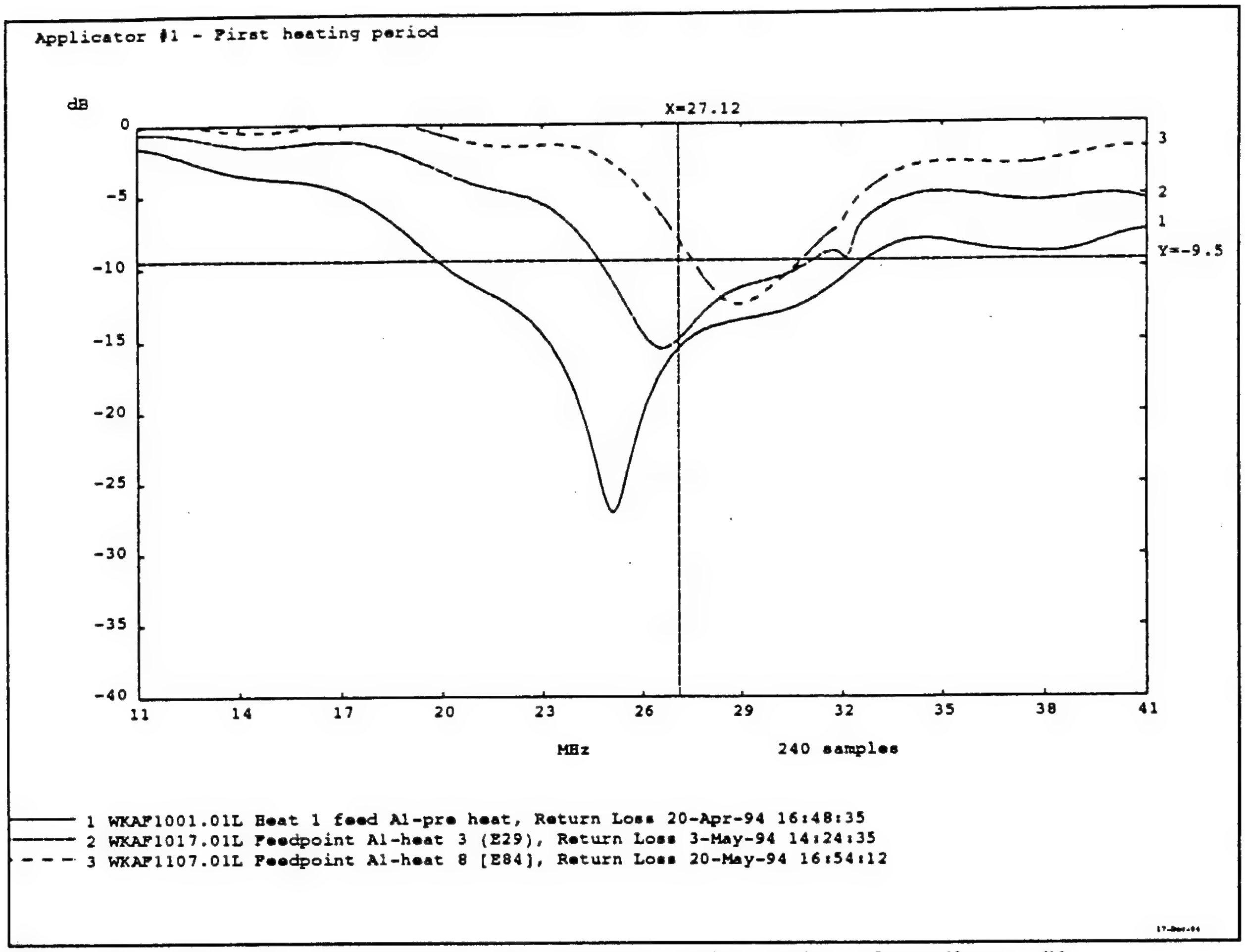

Figure 21 Return loss measurements for the first heating period of Applicator #1.

sampling logs and has been subsequently relabeled well A2 within this report.

Figure 22 shows the return loss plot of applicator #1 in the cooling soil, prior to restart. It can be seen that the resonance point is about 26 MHz. At the end of the second heating period the applicator resonance point is just below 27 MHz and is quite sharp and deep. This sharp and deep return loss suggests that significant lossy material may have migrated[12] to the vicinity of the applicator well liner during the cooling process.

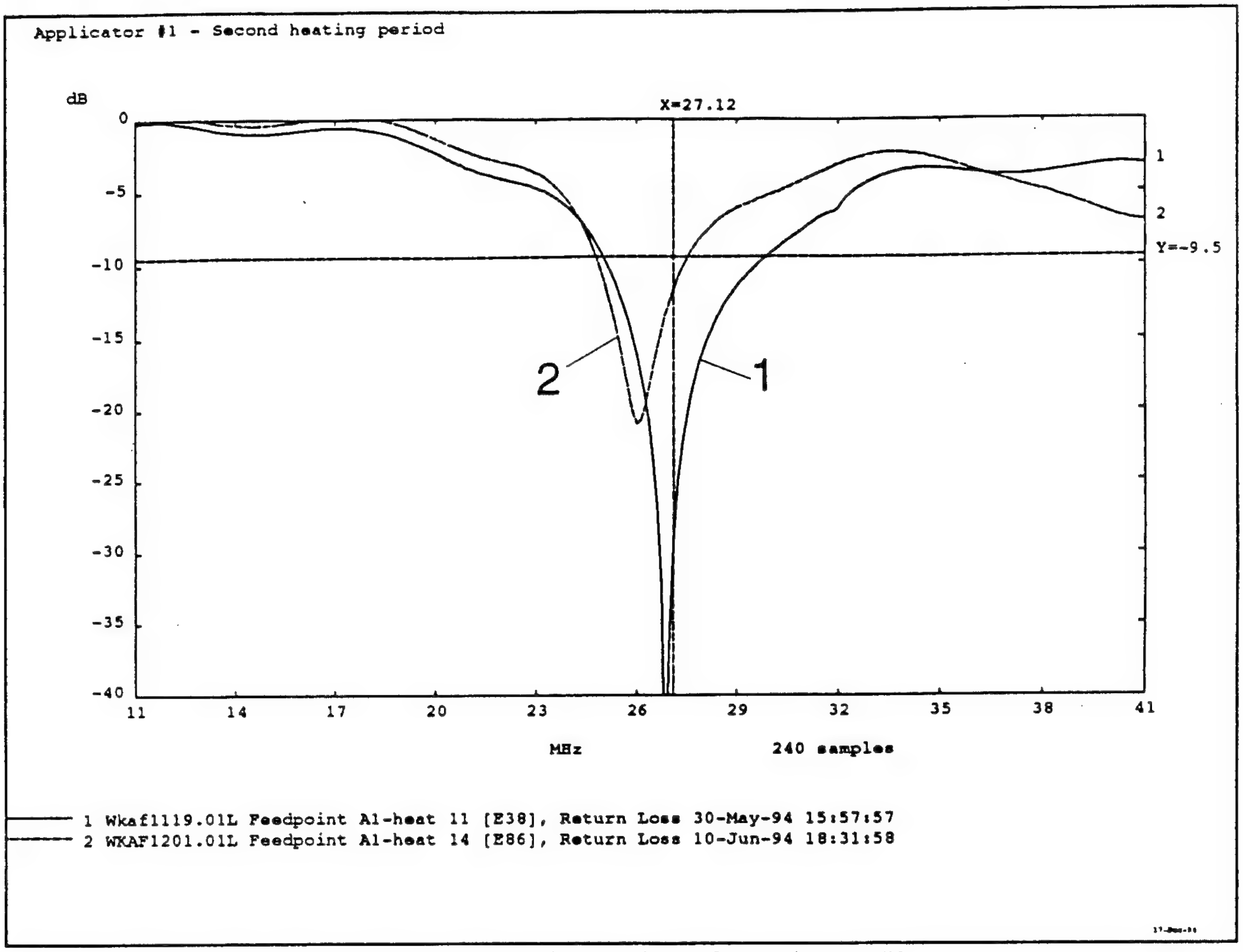

Figure 22 Return loss for the second heating period of Applicator #1.

Figure 23 is a plot of the heating period of applicator #2 which followed the first applicator #1 heating period. Approximately 8 days into the heating cycle, plot line "2" is seen with a resonance above 27.12 MHz. This shift is similar in behavior to that of applicator #1. Shortly after this measurement the applicator failed and was removed from service. The third

[12] This is a speculation based on the idea that the 233 deg C temperature zone about the applicator at the end of heating period one was associated with the flow of a hot, high boiling point liquid. It is possible that the liquid moved into the vicinity of the heating well from an outer location and distributed itself along part of the well wall.

plot, line "3", was recorded after the applicator had cooled for about 9 days.

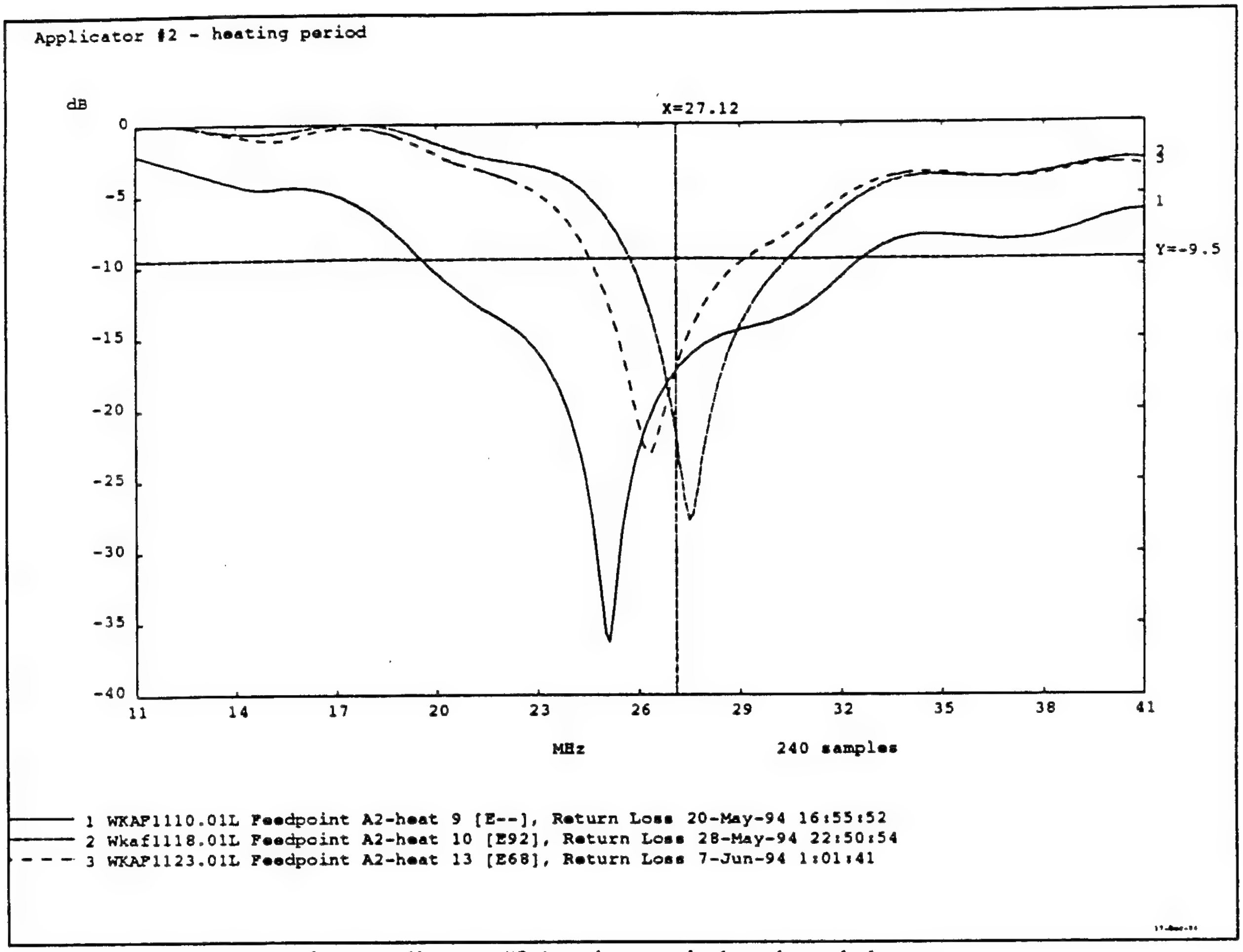

Figure 23 Return loss for Applicator #2 heating period and cool down.

The following observations can be made:

- The heating trends of applicator #1 and #2 were similar but applicator #2 shifted faster in frequency - apparently due to a higher heating rate.

- The cooling trend of Applicator #1 suggested a migration of contaminants back into the heating zone.

- The cooled resonance of the applicator #2 (7 June) heating period is very similar to the cooled resonance of Applicator #1 (30 May) after the first heating period.

5.3.4 Insertion loss trends with heating - These measurements show that as applicator #1 and applicator #2 heat the soil between them, the transmission of energy from one applicator to the other increases. The measurement is typically called the "insertion loss" of the medium between the applicators. It is measured by a network analyzer before and after the heating cycles and is recorded automatically along with the return loss measurements for each applicator. During the heating cycle this property is also measured in real time as a heating diagnostic measurement by the system's vector voltmeter. Figure 24 is a plot of the insertion loss between applicators #1 and #2 before heating. The measurements overlay identically as they should since they measure the same path with the applicators reversed.

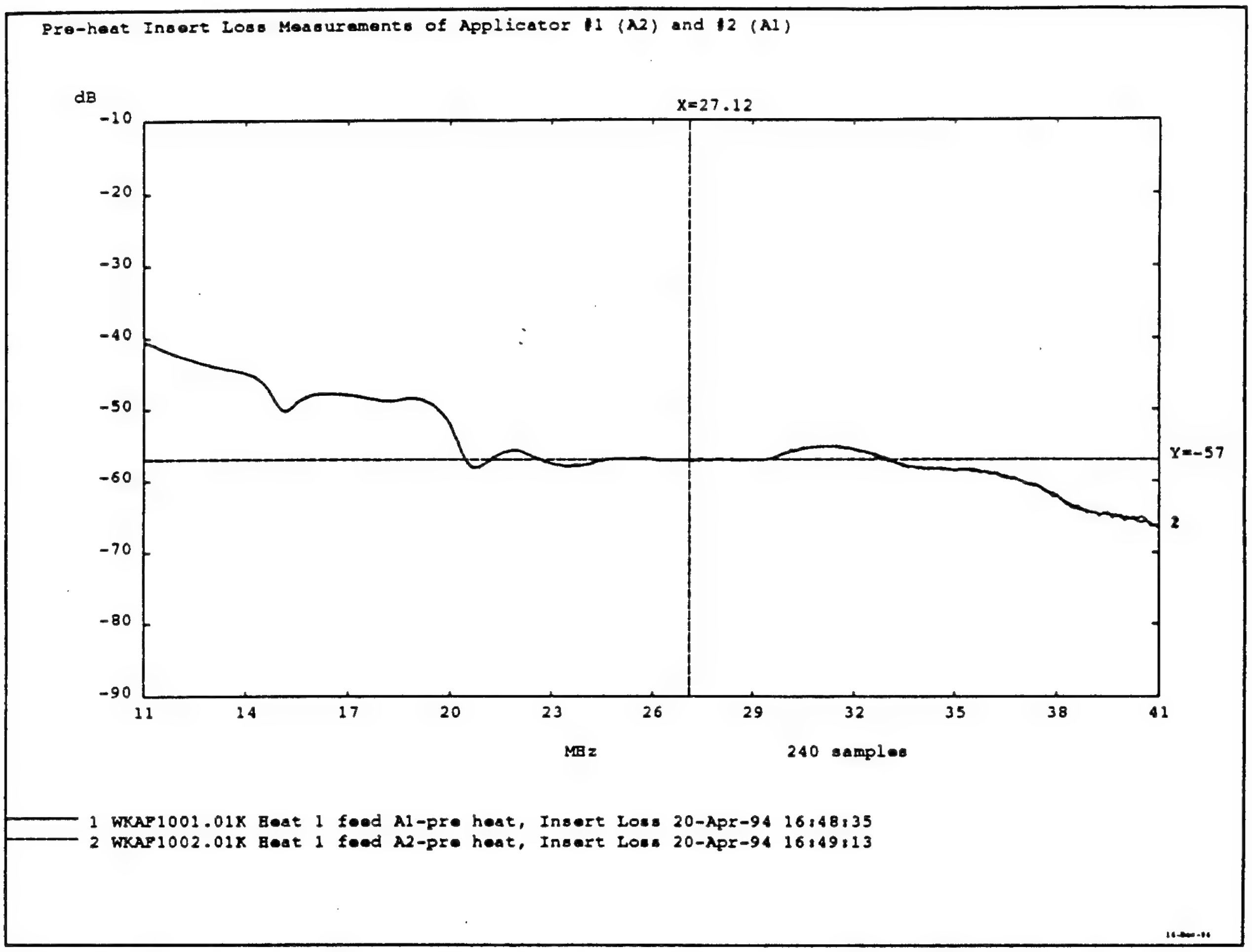

Figure 24 Baseline insertion loss measured between applicators #1 an #2.

Figure 25 shows the Applicator #1 to Applicator #2 measurement as a baseline. This baseline is accented by the -57 dB reference line which corresponds to the initial insertion loss at the 27.12 MHz marker line. This plot corresponds to the first heating period return loss measurement files of Figure 21. In this case it can be seen that there is barely any detectable insertion loss change by 3 May while a noticeable return loss resonance shift occurred. By 20 May a significant (approximately 10 dB) decrease in insertion loss occurred between the

applicators.

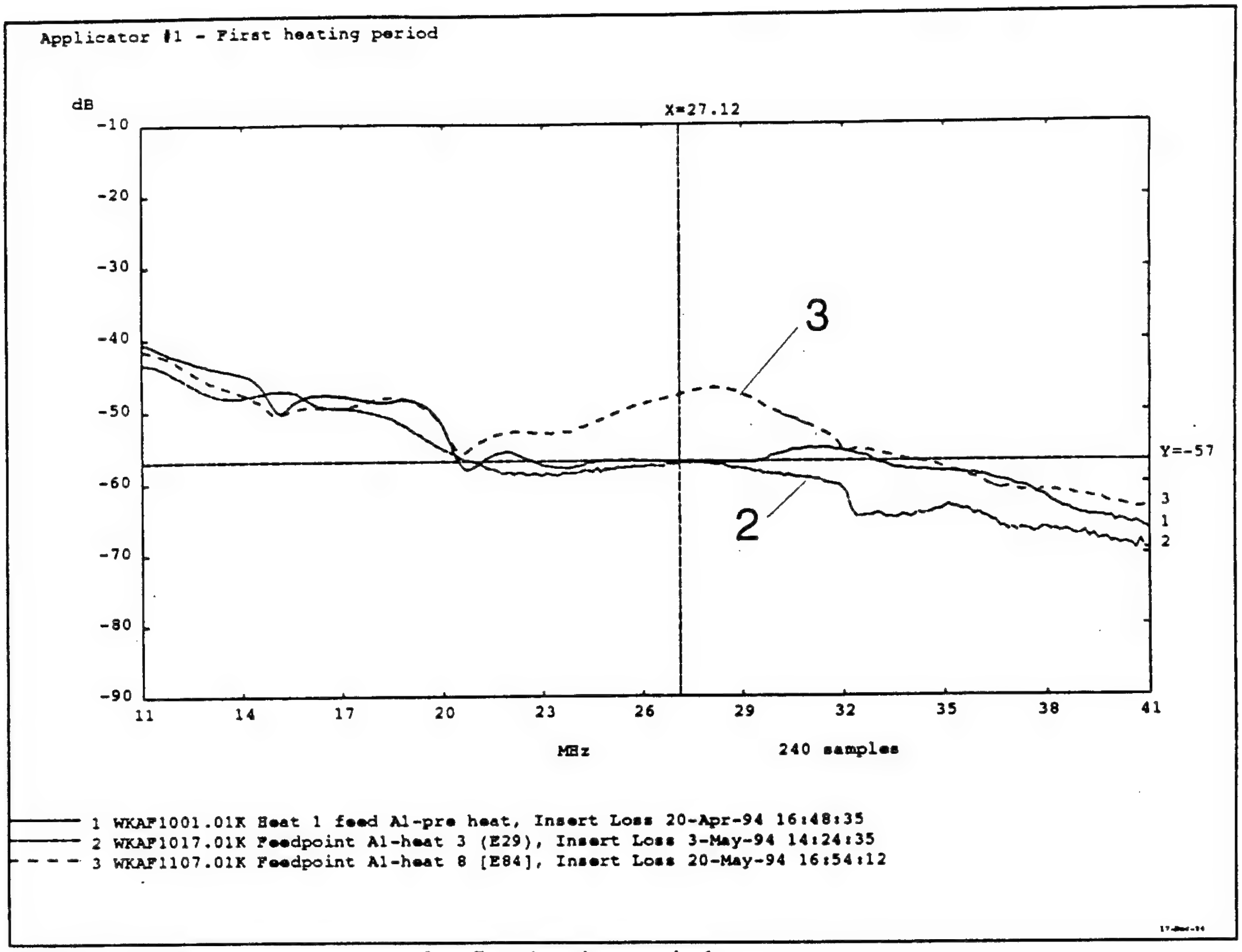

Figure 25 Insertion loss trends for first heating period.

Figure 26 provides insertion loss plots covering the entire program. The trend is continuously in the direction of decreasing insertion loss. At the conclusion of the program the corrected insertion loss decrease was 17.7 dB.

• The highest site level measured at a 10 meter location was 1 V/m for an RF generator output power level of 23.57 kW on 6 June.

• *All RF emission measurements were easily within the compliance limits of FCC Part 18.305 regulations.*

5.4.2 Surface field strength safety measurements - The emissions from the site were measured with the calibrated electric and magnetic probes of a broadband isotropic field strength meter. Radial distances of 0.1 meter, 1 meter and 3 meters from the active heating applicator (A1 or A2) were used as measurement locations. The 10 meter distance measurements from the RF emission tests of 5.4.1 were also included in the radiation safety measurement data analysis. Twenty-three electric field measurement sets were taken at defined locations on the site on twenty-three heating days. **Safety compliance was based on maintaining the electric field exposure level for site personal below the 70 V/m calculated value[12] for the permissible exposure limit (PEL).** The PEL is defined as a 6-minute average exposure limit.

Initial measurements were witnessed by Kelly AFB site safety personnel. The isotropic field probe was constantly available for spot safety checks. Site personal were alerted to the presence of RF power delivery to the applicators by red "RF ON" warning lamps[13].

• 10 meter distance measurements at a 2 meter height reported in section 5.4.1 provided a safety cross check for the program. The maximum emitted field level measured was 1 V/m (vertically polarization only).

• 3 meter distance measurements at a 1 meter height ranged from 1 to 14 V/m over the course of the heating program.

• 1 meter distance measurements at a 1 meter height ranged from 7 to 59.1 V/m over the course of the heating program.

• 0.1 meter distance measurements, controlled by a foam spacer ball (FCC defined test fixture), ranged from 25 V/m to 132 V/m. It is important to note that these

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[12] This is calculated for the 27.12 MHz operating frequency using the formula for the 6-minute average exposure limit in AFOSH Standard 161-9, 12 February 1987. This document is contained as Appendix C of the Site Specific Health and Safety Plan for the Radio Frequency Soil Decontamination Demonstration at Site S-1, March 1993.

[13]Two red lamps were mounted on top of RF SW#3 at the edge of the vapor barrier and one red light was mounted on a mast projecting 5 feet above the instrument shelter. The warning lamps were controlled directly by the RF generator's "RF ON" power enabling circuitry. Two yellow "STANDBY" lamps mounted on masts below the red lamp are turned on to show the system is ready to go to the RF ON state under computer control.

measurements are made on the applicator transmission line surface and do not represent a risk to incidental human exposure.

- The highest measurement within 1 meter of the system at a standard height of 1 meter was 59.1 V/m on 9 June with 23 kW of generated RF power.

- *All measurements within 1 meter of the heating applicator were within the 70 V/m PEL required for the program by AFOSH Standard 161-9.*

- *All measurements within 1 meter of the heating applicator were within the 66 V/m maximum permissible exposure (MPE) allowed by IEEE C95.1-1991 Standard for enforcement of non-ionizing radiation safety.*

- An additional ambient RF measurement was logged by the control computer during some heating periods by using the system vector voltmeter. The voltmeter was connected to a calibrated monopole antenna on the roof of the instrument shelter. The received signal level was processed with alarm and warning limits that were used to alert operators in any shifts of the ambient RF that might signal a potential safety problem and shut down the RF generator. No events were recorded for this program.

- Magnetic field readings tracked the Electric field measurements for safety compliance measurements at 1 meter and 3 meter locations due to the near free space locations of the measurements. Magnetic field reading were recorded only for detailed site mapping measurements.

File: Kelly5.A

6.0 DATA ANALYSIS VS MODELING PREDICTIONS

Numerical and analytical modeling tools were used to provide a prediction envelope for the program. It was very necessary to use a series of general assumptions to setup the models since the site is a non-homogenous hydrocarbon waste dump..

6.1 Electromagnetic modeling - Two numerical codes and one analytic modeling code were used for this program. The codes were used to estimate the operating characteristics of the applicators that may be encountered as the site was heated. Ground constant measurements reported by a previous Kelly AFB test program at site S-1 varied widely and suggested stable values only above 100 degrees C. The models also used ground constant values based on the estimated water content of the soil[14].

Numerical Electromagnetic Code 3, insulated wire case (NEC-3I)[15] and a more advanced code 4 (NEC-4)[16] was used extensively to approximate the effects of the ground plane system, borehole liner, applicator spacing and applicator tuning. The goal of the pre-heating modeling was to plan the size of the ground screen, estimate the required adjustment range of the applicator tuning arms and to estimate the energy that was deliverable to the soil.

An analytic modeling code, PAT7[17] was used to quickly approximate applicator tuning trends with changes in soil dielectric constant, soil conductivity and applicator dimensions. The PAT7 models were examined in detail at specific points by the NEC codes.

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[14] *Hardened Antenna Technology, Antenna Engineering Design Handbook for Buried Linear Arrays*, Eyring Research Institute, RADC-TR-89-54, Vol 2, Final Technical Report, May 1989 - KAI Technologies was a supporting subcontractor for the production of this handbook. Appendix B of this handbook contains tables and practical information on ground constants.

[15] G.J. Burke, A.J. Poggo, *Numerical electromagnetics Code* (NEC) - *Method of Moments*, Naval Ocean Systems Center Technical Document 116, January 1981.

[16] G. J. Burke, *Numerical Electromagnetics Code - NEC-4, Method of Moments, Part I: User's Manual*, Lawrence Livermore National Laboratory, January 1992.

[17] M.B. King, R.B. Gilchrist and D.L.Faust, *Eyring Low Profile and Buried Antenna Modeling Program PAT7 User's Manual*, Eyring, Inc. Communications Systems Division, Provo, UT. June 1991. - The PAT7 code was developed to predict the communications performance and characteristics of broadband buried antenna systems. The data from this program can be interpreted to provide insight into the operation and tuning of narrowband RF heating antennas.

6.1.1 NEC modeling of the dual-applicator system for tuning - A series of models were used to approximate various aspects of the applicator tuning problem. The models considered:

- Diameter of applicator in relation to borehole diameter and average ground parameters.

- Influence of the ground plane design on the tuning strategy of the applicator when positioned near the surface. The study suggested ground plane radial lengths and expected surface electric field levels.

- Field strength within the surrounding medium as a function of antenna tuning.

The data sets developed by this approach produced guidance and trends but did not develop predictive values that matched the site's initial conditions prior to those determined by actual on-site measurements. The complete system with two applicators, transmission lines, ground plane and emplacement towers was too complicated to practically model to a predictive degree. The inhomogeneous nature of the contaminated soil added the final complication to the modeling problem.

6.1.2 NEC modeling of driving point impedance and transmission loss changes due to heating - Modeling provided a useful insight into the range of changes that were associated with the heating process. NEC-4 was used to model the change associated with the heating of applicator #1 in well A2. The NEC model was adjusted by changing the average ground constants (over 100 in. span) till the measured transmission loss value recorded at the end of the program was approximated. The result was as follows:

	Impedance (complex value) ohms	**Transmission loss measured between App #1 and App #2 dB at 27.12 MHz**
Applicator #1 (Start 20 April)	49.2 + J16.1	57.4 (measured)
NEC model ($Er=14.75$, $\sigma=40$ mS/m)	56.8 + J12.3	57.1 (starting model)
Applicator #1 (End 10 June)	47.0 + J23.0	39.7 (measured)
NEC model (Er - 8, $\sigma=15$ mS/m)	69.5 + J12.3	39.1 (resultant model)

The 17.7 dB transmission loss decrease associated with the heating process was modeled by shifting the average ground constants until the model matched the loss. The change in ground constants were consistent with a change in volumetric water content from 18% to 5%.

However in this case the shift is most likely due to the removal of hydrocarbon products and not a significant, 18% water content.

6.2 Thermal modeling - The thermal modeling program was used to estimate the thermal propagation characteristics of a single applicator and dual applicator heating system with the same total input power.

A finite element analysis (FEA) heat transfer code model was developed for the COSMOS FEA code developed by the Structural Research and Analysis Corporation. The energy distribution pattern used to drive the model was based on a static NEC-3I model of the RF heating applicators energy distribution for a 100 degree C starting temperature. The model developed 6 thermal calculations over a period of 30 days. Heating was started at 100°C because the electrical properties of the soil, as predicted by the previous program, remained relatively constant above this temperature.

Two cases were modeled at a 27.12 MHz frequency with 20 kW power delivery levels to the soil:

- Single applicator at 100% duty cycle,

- Two applicators spaced 10-feet apart operating at a 50% duty cycle.

6.2.1 NEC-3I configuration for thermal modeling. The single dipole was modeled in the center of a *homogenous*[18] soil volume while the dual applicators were centered on the x-y plane, 10 feet apart. The applicators were operated at their resonant length for the modeled media with the dual dipoles slightly shorter in length due to mutual coupling.

Length (m):	2.75 (9') single; 2.65 (8.7') dual
Diameter (cm):	7.62 (3")
Insulation Diameter - Air (cm):	11.81 (4.65")
ϵr (Soil):	8.0
σ (mS/m):	0.678
Frequency (MHz):	27.12
Feed Depth below Air/Soil Boundary (m):	14.6' single; 14.4' dual
Radiated Power (kW):	20 kW single; 20 kW (10 kW per) dual
Impedance at Resonance (Ω):	53.2 single; 38.8 dual (w/coupling)

[18] NEC-3I requires a homogeneous medium as a modeling assumption. Below 100°C the RF heating process is much more complicated to model because both the electrical and thermal properties are changing as the temperature is raised and as the moisture is driven from the soil.

6.2.2 COSMOS FEA heat transfer configuration. The COSMOS FEA heat transfer model was run using the following values for the soil properties along with the heat flux densities generated by NEC-3I[19]. The model assumed that the soil volume was well insulated.

Dimension of heated volume:	21 ft. x 21 ft. x 21. ft
Soil volume:	343 cubic yards
Specific Heat (c):	0.22 cal/gm/°C
Density (ρ):	1.7 gm/cc
Thermal Conductivity (k):	0.25 cal/m/s/°C

6.2.3 Comparison of modeled to measured data. The heating profile data consists of 4-D color plots and a plot of the temperature versus time at a point 5-foot from the feed point of the applicator (center of antenna at depth). For the case with two applicators this 5-foot point represented the point directly between the feeds of two applicators since the applicators were 10 foot apart. The modeling data sets are provided as Appendix J of this report.

- The dual applicator model describes an ideal intended pattern for the site that may have been approximated if the system were able to alternate power between the applicators and would have been able to operate for the entire program at its optimum heating rate.

- *In general the modeling data cannot be applied directly to the heating program as it developed at the Kelly AFB site.*

- The segmented and low rate heating periods make it difficult to draw any direct ties to the time scale of the modeling with the actual program.

- The non-homogenous electromagnetic and physical nature of the soil further confounded any efforts to relate measured data to the thermal model. The 3-D return loss plot of A2 in section 5.3.1 confirms this observation from the electromagnetic view..

- The model suggests that higher temperatures should have been seen on the lower half of the applicators but they were observed to be higher on the upper half of the applicators. This could be due to the non-homogenous nature of the soil or the cooling influence of the SVE systems flow pattern.

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[19] W.C. Walton, *Principles of Groundwater Engineering*, Lewis Publishers, Inc. 1991

7.0 REVIEW OF SOIL CHEMICAL ANALYSIS

The soil chemical analysis scheme was originally based on the definition of a Treatment Zone volume of 111 cubic yards (15 ft. x 10 ft. x 20 ft.) which was compared to a control sample region bounding the sides of the volume with sample depths up to 10 feet below the region. The soil analysis for Total Recoverable Petroleum Hydrocarbons (TRPH) was based on the analysis of 40 sample pairs within this region.

Due to changes in the heating system configuration, a heating zone of 15 ft. x 10 ft. x 10 ft. was defined inside of the treatment zone. The top of the zone starts at a depth of 4 feet and ends at a depth of 14 feet. This zone was further subdivided for analysis into two a halves. The halves are centered about each of the heating boreholes (A1 and A2). The TRPH analysis if these zones, with an 80% confidence level correlates with the energy applied to the zone and the period of the applied energy (heating).

	Volume	TRPH	Energy delivered	Days spanned
Treatment zone	111 cu. yds.	29%	15,549 KWH	49.92
Heating zone	55.5 cu. yds	>42%	15,549 KWH	49.92
A1 heating zone	27.7 cu. yds	<40%	4,348 KWH	8.15
A2 heating zone	27.7 cu. yds	>60%	11,201 KWH	41.77 (2 spans w/cooling period)

(!!! NOTE: The above ">" items are estimated place holders, pending new calculations by SAIC, 12/14)

The A2 heating zone, driven by applicator #1 is suggestive of the anticipated recovery rate. Ideally this zone and the A1 zone would have each received 10,000 KWH in a 42 day period. It is projected that this heating would have been more effective than the slow heating period with cooling cycles that this program experienced. It is also expected that if a second generator were used the simultaneous, phased-array heating would produced an even stronger and rapid heating effect that would further improve recovery. Finally, changes to the SVE system design would also be a source of recovery improvement.

7.1 Impact of changes in the heating system configuration. - Changes in the heating program's planned operating time and its ISM operating frequency required that the heating zone be defined as approximately upper half of the treatment zone. This change occurred when an ISM operating frequency of 27.12 MHz was chosen in contrast to a 13.56 MHz frequency. The 27.12 MHz frequency was chosen to allow a faster heating of two smaller adjacent volumes within the treatment zone as opposed to a larger heating zone with a slower heating rate.

The 13.56 MHz applicator would have had a nominal heating span of 18 ft. as opposed to the 9 ft. span of the 27.12 MHz applicators and could have been positioned within the center of the treatment zone. Two, more rapidly heating, 27.12 MHz applicators were chosen to be driven in a time-multiplexed heating mode by a single 25 kW RF generator to approximate the performance of a more optimally configured dual RF generator system. This

configuration allowed data to be gathered that would be predictive of how a dual RF generator phased-array[20] RF system might perform.

A additional impact of the shorter, vertical profile, heating span occurred when the applicator was fixed in the upper half of the treatment volume. This upper half favored the heating of VOCs as opposed to SVOCs in the lower half of the treatment zone.

(DRAFT NOTE) - The detailed chemical analysis commentary and data has not been fully available for review as of this time. Comments, as required by the program SOW, will be provided in review of the Final Program Report.

7.2 Other operating details with soil analysis influence - The SVE system typically operated in a "deep extraction" mode that pulled vapors down from the bottom of the heating zone into the extraction wells screened from 10-ft. to 20-ft. depths (see 3-D site setup figures in Section 2.0 and Appendix B SVE configurations listed in logging comments). The effect of this downward vapor "draw" may be responsible for some contaminant migration from the heating zone into the treatment zone and is likely to make it difficult to quantitatively evaluate contaminate concentration changes.

Several of the statistically defined TRPH sample sets[21] were complete enough at test well location to be examined as a concentration profile. A review of some TRPH sample sets suggest that materials condensed between the 0-foot and 4-foot levels where the SVE efficiency may have been low. Condensation also appears to have occurred where hot and cool extraction air mixed near an extraction well. The following data listings are of three set of soil samples. Missing depths were omitted due to the statistical sampling scheme used to distribute the 40 sample pairs..

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[20] A 2-element phased applicator array actually has a heating rate and intensity advantage over what can be produced by two, non-phase controlled applicators and RF generators. This testing approach provided data to evaluate how well the base heating rate could be predicted for the non-phased applicators. The test also demonstrated the electromagnetic field coupling levels that could be achieved between the two applicators.

[21] ***** **AS OF THIS DRAFT THE VALUES PRESENTED HERE ARE PRELIMINARY AND WILL BE REPLACED BY FINAL VALUES BY SAIC.**

A2 - Location of applicator #1 with the majority of applied energy - The 0 - 4 ft. locations show significant increases in concentration. The heating zone volume near the applicator shows a strong removal trend. The 10 - 12 ft. location that corresponds to the highest heating temperature profile shows significant removal.

Location A2	Pretreatment Concentration (ppm)	Post treatment Concentration (ppm)
0 - 2 ft.	2,330	8,850 [suggested condensation]
2 - 4 ft.	203	2,570 [suggested condensation]
-------- heating zone boundary -----		
4 - 6 ft.	1,530	154
6 - 8 ft.	-	-
8 - 10 ft.	-	-
10 - 12 ft.	1,290	33.3 [removal to quantitation limit]
12 - 14 ft.	622	106
-------- heating zone boundary -----		
14 - 16 ft.	-	-
16 - 18 ft.	79,700	20,800
18 - 20 ft	39,300	28,300 [removal by ambient air SVE only]

E5 - Extraction well located on center line near A2 - Extraction is enhanced in the heating zone. The 12 - 14 ft. level appears to a condensation boundary were cool air meets the downward flow of hot vapor.

Location E5	Pretreatment Concentration (ppm)	Post treatment Concentration (ppm)
0 - 2 ft.	-	-
2 - 4 ft.	-	-
-------- heating zone boundary -----		
4 - 6 ft.	2,710	673
6 - 8 ft.	1,530	587
8 - 10 ft.	-	-
10 - 12 ft.	668	330
12 - 14 ft.	739	1,450 [suggested condensation at extraction well]
-------- heating zone boundary -----		
14 - 16 ft.	-	-
16 - 18 ft.	-	-
18 - 20 ft	105,000	35,800 [removal by ambient air SVE only]

F3 - Monitor hole for IR temperature profiles centered between A1 and A2 at 5 feet. - Strong removal is suggested in the top of the heating zone where the maximum temperature profiles were recorded between 6 and 10 ft. The temperature dropped off sharply in the 10 ft. to 12 ft. zone and could be seen to match the region of increased concentration.

Location F3	Pretreatment Concentration (ppm)	Post treatment Concentration (ppm)
0 - 2 ft.	-	-
2 - 4 ft.	-	-
-------- heating zone boundary -----		
4 - 6 ft.	4,920	702 [strong removal suggested]
6 - 8 ft.	-	-
8 - 10 ft.	-	-
10 - 12 ft.	336	4,510 [suggested condensation between extraction wells screened from 10 ft. to 20 ft.]
12 - 14 ft.	-	-
-------- heating zone boundary -----		
14 - 16 ft.	-	-
16 - 18 ft.	-	-
18 - 20 ft	-	-

7.0 REVIEW OF SOIL CHEMICAL ANALYSIS

The soil chemical analysis scheme was originally based on the definition of a Treatment Zone volume of 111 cubic yards (15 ft. x 10 ft. x 20 ft.) which was compared to a control sample region bounding the sides of the volume with sample depths up to 10 feet below the region. The soil analysis for Total Recoverable Petroleum Hydrocarbons (TRPH) was based on the analysis of 40 sample pairs within this region.

Due to changes in the heating system configuration, a heating zone of 15 ft. x 10 ft. x 10 ft. was defined inside of the treatment zone. The top of the zone starts at a depth of 4 feet and ends at a depth of 14 feet. This zone was further subdivided for analysis into two a halves. The halves are centered about each of the heating boreholes (A1 and A2). The TRPH analysis if these zones, with an 80% confidence level correlates with the energy applied to the zone and the period of the applied energy (heating).

	Volume	TRPH	Energy delivered	Days spanned
Treatment zone	111 cu. yds.	29%	15,549 KWH	49.92
Heating zone	55.5 cu. yds	>49%	15,549 KWH	49.92
A1 heating zone	27.7 cu. yds	<27%	4,348 KWH	8.15
A2 heating zone	27.7 cu. yds	>47%	11,201 KWH	41.77 (2 spans w/cooling period)

(!!! NOTE: The above ">" items are estimated place holders, pending new calculations by SAIC as of 12/14 ---- 27% and 47% values are in question due to F3 inclusion?)
The A2 heating zone, driven by applicator #1 is suggestive of the anticipated recovery rate. Ideally this zone and the A1 zone would have each received 10,000 KWH in a 42 day period. It is projected that this heating would have been more effective than the slow heating period with cooling cycles that this program experienced. It is also expected that if a second generator were used the simultaneous, phased-array heating would produced an even stronger and rapid heating effect that would further improve recovery. Finally, changes to the SVE system design would also be a source of recovery improvement.

7.1 Impact of changes in the heating system configuration. - Changes in the heating program's planned operating time and its ISM operating frequency required that the heating zone be defined as approximately upper half of the treatment zone. This change occurred when an ISM operating frequency of 27.12 MHz was chosen in contrast to a 13.56 MHz frequency. The 27.12 MHz frequency was chosen to allow a faster heating of two smaller adjacent volumes within the treatment zone as opposed to a larger heating zone with a slower heating rate.

The 13.56 MHz applicator would have had a nominal heating span of 18 ft. as opposed to the 9 ft. span of the 27.12 MHz applicators and could have been positioned within the center of the treatment zone. Two, more rapidly heating, 27.12 MHz applicators were chosen to be driven in a time-multiplexed heating mode by a single 25 kW RF generator to approximate the performance of a more optimally configured dual RF generator system. This

8.0 REVIEW OF SOIL VAPOR EXTRACTION DATA

The soil vapor extraction system flow characteristics do not appear to have been optimum to extract from the chosen Heating Zone in the upper level of the site Treatment Zone (see site setup in Section 2.0). However, it appears that they were adequate to demonstrate significant VOC removal from the Heated Zone.

The downward "draw" of the SVE system on the Heated Zone has been observed to produce a number of thermal profile measurement distortions that require careful analysis for interpretation. In general the downward flow caused the deep portions of the thermal patterns to have lower relative temperature values and truncated profile patterns with minimal lateral flow and limited "draw" from the higher levels of the zone. It is also possible that condensation occurred for some volatiles as they mixed with cooler air as they were drawn to the extraction wells.

The SVE system output temperatures, measured at the control valves next to the vacuum manifold, were generally lower than anticipated. Temperatures within the heated zone suggested that high temperature soil vapors could be estimated to range from 100 degs C to well over 180 degrees C. These vapors were mixed with a significantly larger[22] volume of cooler subsurface air that maintained the extraction well output temperatures below 100 degrees C.

The six SVE sampling periods reported Radian are identified along with the site heating conditions and SVE configuration in the comments section of the Appendix B logging summary. The SVE temperatures versus time plots are plotted in Appendix H.

(DRAFT NOTE) - The detailed SVE analysis commentary has not been fully available for review as of this time. The Radian report has been reviewed but not in the context of temperature and SVE flow profiles that are still being evaluated. Comments, as required by the program SOW, will be provided in review of the Final Program Report.

Page 5-15 of the Radian report[23] indicates that the lowest SVOC and VOC concentrations were measured on 14 June. This was 4 days after the RF system was turned off (report indicates 7 days in error). The report suggested that this measurement constituted an anomaly when

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[22] The conclusion is arrived at by estimating that the top 1/3 of each extraction well (10 ft. to 13 ft.) received hot vapors and the balance of the well (13 ft. to 20 ft.) contributed cooler subsurface air to the extracted air stream. In cases where multiple extraction wells were connected the dilution ratio would be still higher.

[23] *KAI Technologies Inc. Radio Frequency Heating Demonstration - Final Report*, Radian Corp., Austin TX, September 7, 1994.

compared with the following 24 June measurement of comparatively higher values. Actually this shift appears to be due to the SVE configuration shift on 14 June.

The previous measurement on 7 June was made with an identical SVE configuration to the one on 14 June. Both measurements used only the deep extracting center-line wells E4 and E5. All other wells, on the perimeter of the site were used as injection wells. The SVE shift on 14 June cut off extraction form E4 and E5 and only drew from the East Wall E1, E2 and E3 wells which essentially reversed flow on part of the extraction volume.

9.0 COST EVALUATIONS

The Kelly RF Heating program was essentially executed as an investigative pilot program that addressed an number of site configuration items (e.g. SVE) in addition to the RF heating system installation and operation. The site was operated with more personnel than would normally be required for even a larger program and site conditions did not allow full automatic operation of the heating system. Therefore it is not easy to develop a set of directly scaled cost figures that apply in detail to a commercial embodiment of this system.

However, there are some cost and resource utilization number available, directly from the program data that can be used to generally characterize the application of RF heating for thermally enhanced SVE programs. These numbers were based on the last 21.3 day period[24] of the heating program. These planning numbers are:

- RF Energy Generation rate: (dependent on available 3-phase voltage level). — 19.93 kW/hour
- Cost per hour of RF generated: (based on a 19.93 kW/hr generation rate with a 58.9% system 3-phase AC power conversion efficiency plus 5 kWH overhead with a utility rate of $0.10/kWH) — $3.88/hour
- RF system operation within on site span: (includes breaks for measurements and maintenance checks over a span or 10 days or more). — 94.54%

9.1 Outline for costing of a 200 kW system - A 200 kW system could be approached by using eight 25 kW RF generators with the capability of driving either 2-element or 4-element applicator arrays. The system would employ a minimum of 16 switched applicator positions to allow continuous operation of the system as applicators are removed from heated areas and installed in new areas.

The exact definition of a 200 kW system will depend on the site characteristics. Some of the principal determinates of the system configuration would be:

- Contaminant plume thickness, extent and nominal depth defines if the preferred access would be through either vertical or horizontal drilling techniques.

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[24] This period follows the repairs to the 3-phase power system splices and replacement of the power line.

• The preferred heating dimensions of the plume will determine if the RF heating system's operating frequency should be 13.56 MHz with a nominal heating span of 18 ft. or 27.12 MHz with a nominal span of 9 ft. In some applications is possible to operate with a 6 ft. span at 40.68 MHz. In some cases the heating rate of the plume will be a factor in contrast to SVE flow requirements. An ISM heating frequency of 40.68 MHz heats the smallest volume most rapidly and 13.56 MHz heats the largest volume more slowly.

• The need or option to access large volumes of the contaminant plume also determines if the system needs large numbers of installed applicators with switching networks to allow efficient, automated operation. Alternately a limited number of applicators, with mechanical positioning equipment, can incrementally heat large volumes of the plume from a few borehole (e.g. horizontal).

9.2 A 200 kW system description - The following system would be defined as a wide coverage 13.56 MHz system configured for horizontal drilling emplacement. It would have the following components:

2	RF Master control and instrument trailers with an internally mounted 25 KW, 13.56 MHz RF generator and tuner (the units would be similar in size and design to the KAI pilot Rig #1 used for this program). Each master control trailer would also carry control and diagnostic instrumentation. The master control systems would be linked with the slave systems through fiber optic cables. Each master control system would be fully automated and respond to both local and remote control computer commands.
2	Slave RF systems with three 25 kW, 13.56 MHz RF generators and tuners per trailer. Each slave trailer would include a common cooling system and 3-phase AC power distribution system.
16	Flexible horizontal applicators with an emplacement system allowing controlled motion during heating of up to 45 ft. per setup.
8	Motorized RF switches to select between two installed applicators that are to be selected by each RF generator/tuner group.
--	Flexible and rigid RF transmission line suitable to reach 16 heating locations from the two trailer groups.
1	3-phase AC power utility or Diesel generator service capable of providing a minimum of 500 kVA for the site. Additional power requirements would dependent on the requirements of the SVE and off gas treatment systems.

A heating system of this scale and capital investment[25] can be expected to operate in the field with utility power costs, full automation, and programmed personnel support for configuration changes at a cost of much less than $100 per cubic yard over a multi-year operating period. This figure is exclusive of horizontal drilling costs, SVE system installation, off gas treatment and non-RF site operating costs.

9.3 Recommendations on system strategies - The costing of RF thermally enhanced SVE programs is very dependent on the use of the following key strategies:

- Select the ISM heating frequency based on the optimum heating rate, soil penetration depth, and contaminant thickness.

- Select a drilling technique (vertical, slant or horizontal) that provides the most access to the contaminated zone for each borehole position and applicator heating span.

- Use each heating applicator in multiple positions along the length of the guide tube or slowly "scan" the heating zone with the applicator's heating span.

- Use each RF generator to sequentially drive two or more applicators.

- Use multiple RF generators in groups of two or four as phased arrays to focus and steer heating pattern.

- Use automated and remote control operation to minimize the need for highly skilled on-site labor.

The application of RF thermal enhancement also needs to be characterized in terms of the time savings it represents over conventional treatment projections using non-thermal SVE technique at the same site (assuming the targeted contaminants are removable by non-thermal methods). Key points for consideration are:

- RF thermal enhancement can be applied as a rapid response tool for stopping the migration of contaminant plumes at depths of over 750 feet.

- RF thermal enhancement may be selectively applied to high concentration regions within a general site remediation strategy of passive SVE.

- Thermally enhanced SVE may allow extraction of contaminates from some sites that normally would require excavation.

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[25] Assuming a 5 year pay pack period.

Data Appendices

A - Site data logging - TAQR program channel listing and channel details.

B - Heating Summary - Site statistics and heating cycles with log comments

C - Power Measurements - AC and RF power plots

D - Temperature Plots - Fiber optic probes

E - Temperature Profiles - Thermocouple measurements

F - Temperature Profiles - Infrared probe measurements

G - RF System Matching Measurements - return loss and insertion loss.

H - RF System Emission Measurements - RF emission compliance under FCC part 18.305 and surface field strength compliance under (IEEE standard C95.1-1991).

I - Plots of SVE and Heating System - displayed on the RF heating system time line.

J - Thermal Modeling Data - One and two applicator models.

APPENDIX A - Site data logging

The typical 23 channel data accusation and control screen for the KAI RF Heating control and monitoring system is shown below. Description of the channel groups and screen display features and program capabilities follow. The typical TAQR[21] data acquisition screen looks like this:

```
18-May-94 18:49:21.2  TKEL0824.46   Elapsed= 47:59:42   Remain= 0:00:18
Transmitter:  RF ON     (Steady)          X=Xmit Q=quit Sky ON
 1  Gen. AC input PWR                                           30.07 kW
 2  Gen. RF PWR Incident                S                       19.35 KW
 3  Gen. RF PWR Reflected               SHX                     145.25 Watts
 4  Gen FWD cpl VVM 27.12MHz                                    109.2 dBuV
 5  App FWD cpl VVM 27.12MHz                                    109.2 dBuV
 6  App REV cpl VVM 27.12MHz                                    100.4 dBuV
 7  App REFL cpl VVM 27.12MHz                          -0.1804 -0.3151
 8  SW#3 REF FWD CPL 27.12MHz                                   109.7 dBuV
 9  S3 P B 27.12MHz                     HX                      108.1 dBuV
10  S3 R PB 27.12MHz                                   0.2701 0.7867
11  Gen. O.L. RESET ALARM=0             LX                      1
13  VAC ch 1 (BLU-RED)                                          210.56 VAC
14  VAC ch 2 (RED-BLK)                                          211.43 VAC
15  VAC ch 3 (BLK-BLU)                                          209.43 VAC
16  VAC 1-phase(wye BLU-N)                                      121.65 VAC
17  INPUT AIR TEMP                                              29.48 deg C
18  OUTPUT AIR TEMP                     H                       79.11 deg C
19  TUNER AIR TEMP                      HX                      34.41 deg C
20  App. manifold                       L                       12.44 PSI
21  APP#1 WALL @10.5'(s)                SHX                     110.53 deg C
22  APP#2 WALL @10.5'( )                HX                      24 deg C
23  App#1 EL at 6.5'(s)                 HX                      141.97 deg C
24  F3 center at 6.5'(s)                SHX                     67.76 deg C
```

The header block is described as follows:

18-May-94 18:49:21.2 TKEL0824.46 Elapsed= 47:59:42 Remain= 0:00:18
This line carries the start time of the data acquisition file group TKEL08*ch.cc* where *ch* is the last channel acquired and *cc* in the continuation number that increments with each file set storage. The elapsed time is from the start time and the remaining time is based on the total number of hours selected for this data run.

Transmitter: RF ON (Steady) X=Xmit Q=quit Sky ON
This line indicates that the RF generator output is set for a steady output level (as opposed to a pulsed or D/A controlled level). X=Xmit and Q=Quit are reminders to operator for the access of hidden menus in the display and Sky ON indicates that the system will report Status and Alarm conditions to the SkyPager over the cellular phone link.

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[21] TAQR or "Timed Acquisition" is a specialized program written in the TBASIC® language by the Communications Systems Division of the Eyring Corporation of Provo, Utah for KAI Technologies Inc. The core program has been evolved by KAI for specialized RF heating tasks.

The typical definitions of the channel groups and individual channels for this program follow[22]. Note that each channel is stored in typically 180 sample groups every hour.

Detailed Channel Descriptions for KELLY AFB tests using TKEL08 setup example:

1	**Gen. AC input PWR**		30.07 kW

This is a measurement by a true RMS AC Watt transducer located inside of the RF Generator cabinet that is scanned by the HP 3457A voltmeter. This is an absolute measurement of the energy being supplied to the RF Generator by the 3-phase power line. However, it is not a measurement of the total system energy input which includes the RF generator stepup blower, air conditioning, heat exchanger pump, lighting, instrumentation, and communications. Typically these items add another 8 to 15 kW to the system's energy requirements.

2	**Gen. RF PWR Incident**	**S**	19.35 KW
3	**Gen. RF PWR Reflected**	**SHX**	145.25 Watts

These channels record the output power (Incident) and reflected power of the generator as sensed by the RF generator's internal directional coupler that is used for automatic power control. These transducer channels parallel the readings of the analog meters on the top left side of the RF Generator cabinet. The transducers are scanned by the HP 3457A voltmeter. The voltages recorded here are scaled and table processed by the TAQR program using lookup table MEAS25 and MEAS26. NOTE: at this time the fit is not perfect and additional interpolation points must be added. This measurement is estimated to be accurate on the order of +/- 4%.

The "S" before the reading indicates that this value is a channel that is used to compose the SKYPAGER status message for remote monitoring of the system. The "HX" indicates that this channel is monitored for a high level alarm that will shut down the RF generator ("X").

4	**Gen FWD cpl VVM 27.12MHz**	**109.2 dBuV**
5	**App FWD cpl VVM 27.12MHz**	**109.2 dBuV**

These channels record the same forward power information as channel 2 but at two other points in the system using -70 dB directional couplers monitored by an HP 8508A vector voltmeter. Channel 4 is measured at Coupler #1. This is at the output of the RF generator before the transmission line segment to RF switch #1 that selects either the input to the applicator tuning network or the dummy load. Channel 5 is measured at Coupler #2 which is located after the applicator tuning network and in the transmission line path to the heating applicator.

The measurements are recorded in the native scale of the vector voltmeter and are scaled to dBm or Watts by post processing of the data files. This measurement is a more accurate measurement of power output than that of channel 2.

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[22] Note that some channels were added during the startup of the program. Not all channels were continuously recorded. In some cases the definitions were changed to reflect configuration changes (typically fiber optic probe selections or locations).

6	**App REV cpl VVM 27.12MHz**		**100.4 dBuV**
7	**App REFL cpl VVM 27.12MHz**		**-0.1804 -0.3151**

Channels 6 and 7 are paired with the channel 5 forward measurement to derive a reflected power measurement and a complex reflection coefficient. Both signals are post processed for analysis. Note that the difference between channel 5 and 6 in dB is return loss.

8	**SW#3 REF FWD CPL 27.12MHz**		**109.7 dBuV**
9	**S3 P B 27.12MHz**	**HX**	**108.1 dBuV**
10	**S3 R PB 27.12MHz**		**0.2701 0.7867**

Channels 8, 9 and 10 are measurements used to determine the transmission characteristics that exist between the heating applicator and the monitoring applicator. Note that channel 8 is corrected by 70 dB and channel 9 by 20 dB to derive the relative transmission loss of 51.6 dB in this case.

11	**Gen. O.L. RESET ALARM=0**	**LX**	**1**

This is a channel to track the status of four overload sensors within the RF generator.

13	**VAC ch 1 (BLU-RED)**	**210.56 VAC**
14	**VAC ch 2 (RED-BLK)**	**211.43 VAC**
15	**VAC ch 3 (BLK-BLU)**	**209.43 VAC**
16	**VAC 1-phase(wye BLU-N)**	**121.65 VAC**

These four channels monitor the 3-phase and 1-phase power voltages used by the system. Channels 13, 14 and 15 are derived from AC to DC voltage transducers located within the RF generator cabinet. Channel 16 is monitored at the RF switching and interlock junction box and also indicates that power is available to operate the remote RF SW#3.

17	**INPUT AIR TEMP**		**29.48 deg C**
18	**OUTPUT AIR TEMP**	**H**	**79.11 deg C**

These channels monitor the cooling air and exhaust air for the RF generator. The sensors are thermistors that are directly processed to temperature by the HP 3457A system voltmeter.

19	**TUNER AIR TEMP**	**HX**	**34.41 deg C**

This channel monitors the upper cabinet air temperature inside of the matching network (tuner).

20	**App. manifold**	**L**	**12.44 PSI**

This channel monitors the nitrogen pressure the RF power transmission lines.

21	**APP#1 WALL @10.5'(s)**	**SHX**	**110.53 deg C**

This is a fiber optic sensor located 10.5' below the surface of the test site on the outside of the fiberglass borehole liner. The probe is inside of a 0.25" ID Teflon tube. The sensor is located on well liner A2 used for applicator #1.

The depth indicated here is referenced to the base of the aluminum plate above each borehole. The ice bath calibration of this sensor suggests a correction of +1.5 degrees to the reading. This sensor has a factory calibration accuracy of +/- 2 degrees.

22 APP#2 WALL @10.5'( )	**HX**	**24 deg C**

This is a fiber optic sensor located 10.5' below the surface of the test site on the outside of the fiberglass borehole liner. The probe is inside of a 0.25" ID Teflon tube. The sensor is located on well liner A1 used for applicator #2, 10 ft. from Applicator #1.

The ice bath calibration of this sensor suggests a correction of +3.0 degrees to the reading. This sensor has a factory calibration accuracy of +/-2 degrees.

23 App#1 EL at 6.5'(s)	**HX**	**141.97 deg C**

This is a fiber optic sensor located 6.5' below the surface of the test site on top of the aluminum radiating element of Applicator #1. It represents the "integrated" temperature of the borehole liner as it is heated by the surrounding soil. The probe is inside of a 0.1875" OD Teflon tube. The sensor is bowed away from the applicator to touch the borehole liner wall.

The ice bath calibration of this sensor suggests a correction of -2.7 degrees to the reading. This sensor has a factory calibration accuracy of +/-2 degrees.

24 F3 center at 6.5'(s)	**SHX**	**67.76 deg C**

This is a fiber optic sensor located 6.5' below the surface of the test site in fiberglass monitoring borehole F3. The probe is inside of a 0.1875" OD Teflon tube that is coiled to position the sensor against the wall facing Applicator #1.

The ice bath calibration of this sensor suggests a correction of -3.6 degrees to the reading. This sensor has a factory calibration accuracy of +/-2 degrees.

NOTE: This channel is also used for Applicator #2 during its specific heating cycle the same as channel 23.

END FILE: KELLYA.A

APPENDIX B - Site S-1 Heating Summary

The following items are included within this appendix:

- Site statistics
- Comparison of the planned program to actual statistics
- Observations on actual site operation
- Site heating cycles with log comments
- Summary of RF Heat Generation and Delivery to Applicators - Table

Site Statistics

• Antenna #1, Applicator position A2[23]	
Energy applied for first heating period (28.9 day span, both low, medium and high power)	6,482. KWH
Energy applied for second heating period (12.87 day span, high power)	4,719. KWH
Total for 41.77 day span	11,201. KWH
• Antenna #2, Applicator position A1	
Energy applied for only heating period (8.15 day span at medium to high power)	4,348. KWH
○ Total RF energy applied to the heating zone (using 90% delivery efficiency of generated RF energy or a 58.5% conversion efficiency of 3-phase AC to delivered RF energy)	15,549. KWH
• Estimated 3-phase AC input power required (back-calculated using a 65% conversion efficiency from AC to RF)	26,693. KWH
• Estimated total site AC energy usage (5 kW/hr avg. energy overhead for 78 days + RF total)	36,053. KWH
• Total span of KAI on-site support at Kelly AFB (28 March - 13 June system packing)	78. Days
• Total span of heat application (21 April - 10 June RF system shut down)	51.3 Days
• Total span of continuous measured SVE operation (13 April - 24 June SVE system shut down)	72.3 Days

[23] Note that in some data sets and in all site photographs the applicator sleeve A2 is identified as A1. Housing A2 was used with antenna #1 (RF heating applicator).

Comparison of the planned program to actual statistics

- Planned span of heat application (by orig. SOW) 42. Days
- Comparison to planned heat application time 122.% of planned

- Energy delivery based on planned 42 day span 20,098. KWH
  (using actual 19.93 KW/hr best estimated delivery rate w/94.54% ON time operating efficiency)
- Comparison to planned energy delivery 77.3% of planned

Observations on actual site operation

- The earliest date RF heating could have started was by 6 April
- USAF Frequency management allowed medium power operation on 21 April
- USAF authorization for full power operation was granted on 25 April.
  NOTE: It is estimated that 19 Days of possible high power operation was lost due to this administrative delay.

- The RF System was operated below its full power and with limited control capability until 20 May.
  NOTE: 30 Days of high power operation with full automatic control was lost due to faulty CU/AL splices and an under-sized 3-phase power feed line. The average RF generation rate increased from a low of 9.42 kW/hr to 19.93 kW/hr[24] after the repair and retrofit operations.

- UNDER EXPECTED SITE CONDITIONS AND WITHIN THE SAME ON SITE OPERATION SPAN: The System could have operated at full power with an operating period of 15 + 51.3 = 66.3 days. The RF system, if operating at the actually site-documented rate delivery rate of 19.93 kW/hr, could have placed 31,712 KWH of energy into the soil of the heating zone or 200% of what was delivered in this span. This energy could have been distributed throughout the total treatment zone by movement of the applicators.

[24] The 19.93 kW/hr rate is includes normal system OFF and down time for about a 21 day operating period documented on the site from 20 May to 10 June. It also represents a 94.54% RF ON time.

Site heating cycles with log comments
Update: 3 December 1994 analysis

Format for detailed summary of data logging for RF heating program

File name, Title of test, purpose of test
File continuation number span
Start date/time, Day # from 13 April 12:00 AM = Day 0.0
End date

- Hours of data logging represented by this span (from XY file scan of CH 2)
- Heating value, average power generated (CH 2) over entire logging span
- Hours of heating application (CH 2 above 10 kW level), average value.
- KWH generated (heating hours x average value for application)
- KWH delivered to heating soil zone (estimated w/efficiency and calibration correction of 90%)

COMMENTS: general

1. specific numbered items. Including: special site conditions, power outages, repairs, SVE configurations.

SVE SYSTEM STARTED with periodic measurements (by Brown & Root personnel)

Reference time set = 0.00 at start of day

Initial start of continuous SVE measurements, 11:35 Wednesday, 13 April 1994

Note: The SVE system was turned on briefly for system testing before this date and for the initial baseline soil vapor measurements by Radian on 8 April 1994.

COMMENTS:

1. Radian SVE measurement #1 on 8 April, Day -4.5

TKEL00, EM - Applicator #1 in well liner A2, low power short heating tests.

Continuation numbers 01-06

Start 15:44 Thursday, 21 April 1994, Day 8.65

18:45 Thursday, 21 April 1994, Day 8.78

3.01 hours of logging

1.38 kW average power over logging period

0.12 heating hours (above 10 kW) with average value of 13.07 kW

1.5 KWH generated

1.4 KWH delivered

COMMENTS: No heating value for this period.

1. Biconical Antenna for calibrated EM measurements arrives 14:45, 21 April
2. Power tests authorized at 12 KW level by USAF.
3. SVE Extraction wells: E2 (2'-12'), E4 (10'-20' CL), E5 (10'-20' CL)
4. SVE Passive injection: no wells open, draw from surface.

TKEL01 (not used)

TKEL02, EM Test 2 - Applicator #1 in well liner A2, low power and short duration tests.

Continuation numbers 01-07

Start 10:50 Friday, 22 April 1994, Day 9.45

19:36 Saturday, 23 April 1994, Day 10.81

8.77 hours of logging

10.11 kW average power over logging period

5.23 heating hours (above 10 kW) with average value of 12.95 kW

67.72 KWH generated

60.96 KWH delivered

COMMENTS: Some heating value during period

1. First line voltage problem noted as causing control problem for RF Generator.
2. SVE Extraction wells: E2 (2'-12'), E4 (10'-20' CL), E5 (10'-20' CL)
3. SVE Passive injection: no wells open, draw from surface.

TKEL03, EM Test 3 - Applicator #1 in well liner A2 - **Start of heating cycle**

Continuation numbers 01-85

Start 23:19 Sunday, 24 April 1994, Day 11.97

11:28 Thursday, 29 April 1994, Day 16.5

108.16 hours of logging

9.99 kW average over logging period

58.88 heating hours (above 10 kW) with average value of 15.73 kW

926 KWH generated

833 KWH delivered

COMMENTS:

1. Formal start of heating period
2. Power line stability measurements during this period

3. USAF authorizes full power operation during this period.
4. Difficulty in getting RF Generator to cycle ON/OFF under computer due to power line voltage drop problem (AL/CU splice and 00 AL line later found as problem).
5. Data framing problem puts false "low temp" spikes into temperature data, values are Luxtron channel number as 1,2,3 or 4 deg. C.
6. Test of compressed air to cool borehole liner started at approx 20:00 on 28 April
7. Heavy Rain on 28 April about 11:00
8. Heavy rain storms slowed progress from 29 April till 1 May
9. SVE Extraction wells: E2 (2'-12'), E4 (10'-20' CL), E5 (10'-20' CL)
10. SVE Passive injection: no wells open, draw from surface.

TKEL04, Test 4 - Applicator #1 in well liner A2
Continuation numbers 01-47
Start 22:39 Sunday, 1 May 1994, Day 18.94
22:34 Wednesday, 4 May 1994, Day 21.94
71.91 hours of logging
16.46 kW average over logging period
58.28 heating hours (above 10 kW) with average value of 18.18 kW
1,059 KWH generated
953 KWH delivered
COMMENTS:
1. Test started with two 0.25 ID Teflon cooling tubes added to applicator to cool borehole.
2. Continuous operation leads to high temp scaling of output inductor. Inductor pulled and scaled. Later unit was replaced by a 1-turn copper tube unit.
3. RF generator drifts in adjustments, 18.5 kW max power with instability.
4. IPA trips and fluctuations in RF power and RF drop outs without OL trips - later corrected by transformer tap changes and changes to factory settings over tests 5 and 6 (later solved by power line repairs).
5. Cellular phone blockage at: 21:04, 26 April
6. SVE Extraction wells: E2 (2'-12'), E4 (10'-20' CL), E5 (10'-20' CL)
7. SVE Passive injection: no wells open, draw from surface.

TKEL05, Test 5 - Applicator #1 in well liner A2

Continuation numbers 01-39

03:10 Thursday, 5 May 1994, Day 22.13

18:39 Friday, 6 May 1994, Day 23.77

39.48 hours of logging

12.92 kW average

26.67 heating hours (above 10 kW) with average value of 18.23 kW

486 KWH generated

437 KWH delivered

COMMENTS:

1. Cellular phone blockage, 18:45 5 May.
2. Radian SVE measurement #2 on 6 May 1994, Day 23
3. SVE Extraction wells: E2 (2'-12'), E4 (10'-20' CL), E5 (10'-20' CL)
4. SVE Passive injection: no wells open, draw from surface.

TKEL06, Test 6 - Applicator #1 in well liner A2

Continuation 01-99

Start 19:42 Friday, 6 May 1994, Day 23.82

09:45 Wednesday, 12 May 1994, Day 29.40

134.01 hours of logging

14.87 kW average

75.49 heating hours (above 10 kW) with average value of 19.46 kW

1,469 KWH generated

1,693 KWH delivered

COMMENTS:

1. Cellular phone blockages at 23:01 6 May, 23:01 9 May, 10:01 10 May, 18:05 11 May, 19:07 11 May, 7:01 12 May,
2. 9:08 7 May RF OFF but RF ON due to tuning adjust for voltage fluctuations, later transformer tap changed and returning of osc. stage.
3. 0.5" flow meter and higher capacity liner cooling flow installed on 7 May
4. 12BY7A osc. tube V1 replaced (later found to voltage stability problem)
5. System OFF for 3-phase "black" phase line overheating on evening of 20:18 on 10 May during Cont. No. 76.
6. System restart at Cont. No. 77 at 8:56:46 11-May-94 after 3-phase splice change.
7. SVE Extraction wells: E2 (2'-12'), E4 (10'-20' CL), E5 (10'-20' CL); add E3 (10'-20').
8. SVE Passive injection: no wells open, draw from surface

TKEL07, Test 7 - Applicator #1 in well liner A2

Continuation 01-94

12:27 Thursday, 12 May 1994, Day 29.51
16:57 Monday, 16 May 1994, Day 33.70
100.5 hours of logging
19.65 kW average
94.98 heating hours (above 10 kW) with average value of 19.81 kW
1,881 KWH generated
1,693 KWH delivered

COMMENTS:

1. Restart after power outage to replace bad 3-phase power line splices.
2. System off for approx. 4 hours on 13 May after close lighting hit dropped one phase of 3-phase feed from base power grid. 2" of Rain.
3. Cellular blockage 8:01 15 May, 13:01 15 May, 10:01 16 May
4. SVE Extraction wells: E2 (2'-12'),E3 (11'-20), E4 (10'-20' CL), E5 (10'-20' CL) till Friday, 13 May then close E4 and E5 well on center line (CL) of heating axis in morning.
5. SVE Passive injection: no wells open, draw from surface and surrounding volume till sometime before 17:00 on Thursday 12 May when E8 (10'-20') is opened to air.

TKEL08, Test 8 - Applicator #1 in well liner A2

Continuation 00-86

Start 18:49 Monday, 15 May 1994, Day 32.78
13:38 Wednesday, 20 May 1994, Day 37.67
93.82 hours of logging
15.66 kW average
69.66 heating hours (above 10 kW) with average value of 19.85 kW
1,382 KWH generated
1,244 KWH delivered

COMMENTS:

1. First sign of slow nitrogen leak on applicator #1 (in liner A1) at 18:22 20 May.
2. Cellular blockage 17:00 17 May, 23:01 17 May, 7:01 18 May, 8:01 18 May, 10:01 18 May, 12:01 18 May, 13:00 18 May.
3. 9:09:16 20-May-94 -> shutdown Xmit for power line change.
4. Applicator #1 outside liner temp over 231 deg. C. cannot apply more heat with out possible damage to liner.
5. Applicator #1 heating discontinued to allow start of Applicator #2
6. SVE Extraction wells: E2 (2'-12'), E3 (10'-20'); Tuesday, 16 May E5 (10'-20' CL) is added before 12:00.
7. SVE Passive injection: E8 (10'-20')

TKEL09, Test **9** - Start of to Applicator #2 in well liner A1

Continuation 00-93

Start 18:33 Wednesday, 20 May 1994, Day 37.77

19:22 Sunday, 24 May 1994, Day 41.80

96.81 hours of logging

21.09 kW average

94.21 heating hours (above 10 kW) with average value of 21.49 kW

2,024 KWH generated

1,822 KWH delivered

COMMENTS:

1. Start of applicator 2 heating.

2. Spare Nitrogen tank to external manifold for App#2 isolation. Tank #1 is to low to charge line with reserve.

3. SVE Extraction wells: E2 (2'-12'), E3 (10'-20'), E5 (10'-20' CL); Thursday, 21 May E2 and E3 are listed in summary as closed with only E5 open (not confirmed by site log of 21 May or 22 May); Friday, 22 May E1 (10'-20') and E4 (10'-20' CL) added to group of E1 through E5 wells; Saturday, 23 May E1, E2 and E3 are removed from extraction and only E4 and E5 are used for extraction.

NOTE: the E2, E3 and E5 wells are selected around A2. The extraction starts about A1 when the E1 and E4 wells are selected.

4. SVE Passive injection: E8 (10'-20'); Friday, 22 May E6 (10'-20') and E7 (2'-12') are added; Saturday, 23 May E1, E2, E3 are used as injection wells.

TKEL10, Test **10** - Applicator #2 in well liner A1

Continuation 00-92

Start 21:27 Sunday, 24 May 1994, Day 41.89

22:18 Saturday, 28 May 1994, Day 45.42

96.81 hours of logging

20.98 kW average

94.14 heating hours (above 10 kW) with average value of 21.17 kW

1,992 KWH generated

1,793 KWH delivered

COMMENTS:

1. On Saturday, 28 May, Nitrogen pressure seal at applicator feedpoint started a high leakage rate and exhausted nitrogen supply available on site over Memorial day holiday. Operation continued at risk. Low VSWR of applicator at time of seal failure provided an initial safety margin for continued operation.

2. SVE Extraction wells: E4 (10'-20' CL), E5 (10'-20' CL)

3. SVE Passive injection: E1, E2, E3, E6, E7, E8.

TKEL11, Test 11 - Applicator #2 in well liner A1

Continuation 00-38

Start 23:22 Saturday, 28 May 1994, Day 45.97

15:18 Monday, 30 May 1994, Day 47.63

39.93 hours of logging

20.45 kW average

39.13 heating hours (above 10 kW) with average value of 20.82 kW

814 KWH generated

733 KWH delivered

COMMENTS:

1. Normal heating operation continued until between 14:00 and 15:00 hours on Monday, 30 May (Memorial Day) the rising VSWR caused a sustained HV discharge within the transmission line near the applicator feed point. The center conductor heated beyond the systems thermal expansion capability and shorted the applicator. Confirmed by TDR.
2. SVE Extraction wells: E4 (10'-20' CL), E5 (10'-20' CL)
3. SVE Passive injection: E1, E2, E3, E6, E7, E8.

TKEL12, Test 12 - Applicator #1 in well liner A2, Restart

Continuation 00-93

Start 16:24 Tuesday, 30 May 1994, Day 47.63

00:15 Saturday, 4 June 1994, Day 52.01

103.85 hours of logging

20.09 kW average

94.42 heating hours (above 10 kW) with average value of 20.85 kW

1,968 KWH generated

1,771 KWH delivered

COMMENTS:

1. Restart without difficulty. Ambient RF levels measured by CH 9 test channel to base loaded whip antenna.
2. Radian SVE measurement #3 on 31 May 1994, Day 48
3. SVE Extraction wells: E4 (10'-20' CL), E5 (10'-20' CL)
4. SVE Passive injection: E1, E2, E3, E6, E7, E8.

TKEL13, Test 13 - Applicator #1 in well liner A2

Continuation 00-68

Start: 00:24 Saturday, 4 June 1994, Day 52.01

12:43 Tuesday, 7 June 1994, Day 55.02

72.32 hours of logging

21.64 kW average

70.08 heating hours (above 10 kW) with average value of 22.14 kW

1,551 KWH generated

1,396 KWH delivered

COMMENTS:

1. SVE Extraction wells: E4 (10'-20' CL), E5 (10'-20' CL)
2. SVE Passive injection: E1, E2, E3, E6, E7, E8.

TKEL14, Test 14 - Applicator #1 in well liner A2

Continuation 00-88

Start: 02:10 Tuesday, 7 June 1994, Day 55.09

20:15 Friday, 10 June 1994, Day 58.84

90.09 hours of logging (continuing)

19.43 kW average

86.09 heating hours (above 10 kW) with average value of 20.03 kW

1,724 KWH generated

1,552 KWH delivered

COMMENTS: Test concluded the heating program

1. Applicator lowered to new heating zone but limited to 1.87 ft. by an unidentified jamming point.
2. Temp. logging continued several hours after RF power off.
3. Radian SVE measurement #4 on 7 June 1994, Day 55
4. SVE Extraction wells: E4 (10'-20' CL), E5 (10'-20' CL)
5. SVE Passive injection: E1, E2, E3, E6, E7, E8.

TKEL15, Test 15 - Applicator's removed, Cool down period.

Continuation 00-12, (in progress)

Start: 01:24 Saturday, 11 June 1994, Day 59.05

23:21 Saturday, 11 June 1994, Day 59.97

22.14 hours of logging (continuing)

COMMENTS: No heating at this time, only SVE

1. Note that logging time of computer was offset in archive processing error. File dates indicate 10 June when they should be 11 June.
2. Temperature of A1, Channel 21 has dropped 0.74 degrees C in 22.14 hours.
3. Logging of channels 21 and 22 for borehole cooling rate estimates.
4. SVE Extraction wells: E4 (10'-20' CL), E5 (10'-20' CL)
5. SVE Passive injection: E1, E2, E3, E6, E7, E8.

SVE SYSTEM OPERATION ONLY (by Brown and Root personnel)

COMMENTS

1. Radian SVE measurement #5 on 14 June 1994, Day 62
2. SVE Extraction wells: E4 (10'-20' CL), E5 (10'-20' CL); 14 June change to E1, E2 and E3 with E4 and E5 closed (after Radian measurements ?).
3. SVE Passive injection: E1, E2, E3, E6, E7, E8; 14 June changed to E6, E7 and E8 only.

SVE SYSTEM OPERATION CONCLUDED (by Brown & Root personnel)

Stop: Friday, 24 June approx Day 72.5

COMMENTS

1. Radian SVE measurement #6 on 24 June 1994, Day 72
2. SVE Extraction wells: E1, E2 and E3
3. SVE Passive injection: E6, E7 and E8.

Table summary of RF generation and energy delivery to heating zones

Comments on the table information:

1. The DATA SET FILE NAMES are those used by the TAQR data logging program as prefixes for the 23 channels of logged data. The DATA LOGGING START and STOP points cover the time the system is logging.

2. The ELAPSED TIME SUMMARIES summarize either the Start and Stop hours for a logging interval (RF START and HEATING) or the total number of hours for the logging interval (LOGGING, RF OUT GENERATED). The last column is unique in this group since it reports the Average RF output power level for the adjacent columns RF OUT generator hours.

3. The ENERGY SUMMARY columns outline the totals for each logging period. The RF Gen KWH (1) column is based on a multiplication of the RF OUT GENERATED HRS x AVERAGE RF FOR GENERATOR HOURS. The RF ENERGY DELIVERED KWH (2) is 90% of the RF GENERATED KWH (1).

The 90 % value is a composite correction listed in the upper right hand corner of the chart. The 90% is based on a 98% RF transmission line efficiency, a 95% applicator to soil delivery efficiency and a 97% system correction. Note that the system correction is based on a correction for the system power metering.

4. The COLUMN TOTALS sum the values from the individual logging periods. The ENERGY SUMMARY columns provide a summary of the RF energy generated and the estimated amount delivered to the soil.

5. The SYSTEM PERFORMANCE INDICES are calculated to provide indicators for describing system performance.

Logging time / total hours from start - Indicates what percent of time the logging system was recording system performance from the 21 April start date to the 10 June stop date.

RF OUT / total hours from RF start - Indicates the percent of time RF was generated

Heating period / total hours form RF start - Indicates the percentage of the hours from RF start that were for figured into the heating period.

RF OUT / heating period - Indicates the percentage of the heating period that the RF was output.

6. Impact of required repairs and weather delays on RF generation efficiency

RF OUT / heating period (24 April) to the 12 May 3-phase power splice repair; The AVERAGE RF GENERATION for this period is on the same line.

RF OUT / heating period (24 April) to the 20 May 3-phase power line replacement point; The AVERAGE RF GENERATION for this period is on the same line.

RF OUT / heating period from 20 May to the 10 June, after the repairs; The AVERAGE RF GENERATION for this period is on the same line.

Summary of RF Heat Generation and Delivery to Applicators.									
Kelly AFB site S-1									Efficiency
Update: 10 June 1994									& Cal. Corr
									0.9
Data	Data logging		Elapsed time summaries					Energy summary	
Set File Name	Start and Stop points Date	Time	From RF Start Hours	From Heating Hours	System Logging Hours	RF OUT Gen. Hours	Average RF for Gen. hrs	RF Gen. KWH (1)	RF Energy Delivered KWH (2)
TKEL00	21-Apr-94	03:44:00 PM	0.0						
	21-Apr-94	06:45:00 PM	3.0		3.01	0.12	13.07	1.57	1.41
TKEL02	22-Apr-94	10:50:00 AM	19.1						
	23-Apr-94	07:36:00 PM	51.9		8.77	5.23	12.95	67.73	60.96
TKEL03	24-Apr-94	11:19:00 PM	79.6	0.0					
	29-Apr-94	11:28:00 AM	187.7	108.2	108.16	58.88	15.73	926.18	833.56
TKEL04	01-May-94	10:39:00 PM	246.9	167.3					
	04-May-94	10:34:00 PM	318.8	239.3	71.91	58.28	18.18	1059.53	953.58
TKEL05	05-May-94	03:10:00 AM	323.4	243.9					
	06-May-94	06:39:00 PM	362.9	283.3	39.48	26.67	18.23	486.19	437.57
TKEL06	06-May-94	07:42:00 PM	364.0	284.4					
	12-May-94	09:45:00 AM	498.0	418.4	134.01	75.49	19.46	1469.04	1322.13
TKEL07	12-May-94	12:27:00 PM	500.7	421.1					
	16-May-94	04:57:00 PM	601.2	521.6	100.50	94.98	19.81	1881.55	1693.40
TKEL08	15-May-94	06:49:00 PM	579.1	499.5					
	20-May-94	01:38:00 PM	693.9	614.3	93.82	69.66	19.85	1382.75	1244.48
TKEL09	20-May-94	06:33:00 PM	698.8	619.2					
	24-May-94	07:22:00 PM	795.6	716.1	96.81	94.21	21.49	2024.57	1822.12
TKEL10	24-May-94	09:27:00 PM	797.7	718.1					
	28-May-94	10:18:00 PM	894.6	815.0	96.81	94.14	21.17	1992.94	1793.65
TKEL11	28-May-94	11:22:00 PM	895.6	816.1					
	30-May-94	03:18:00 PM	935.6	856.0	39.93	39.13	20.82	814.69	733.22
TKEL12	30-May-94	04:24:00 PM	936.7	857.1					
	04-Jun-94	12:15:00 AM	1040.5	960.9	103.85	94.42	20.85	1968.66	1771.79
TKEL13	04-Jun-94	12:24:00 AM	1040.7	961.1					
	07-Jun-94	12:43:00 AM	1113.0	1033.4	72.32	70.08	22.14	1551.57	1396.41
TKEL14	07-Jun-94	02:10:00 AM	1114.4	1034.9					
	10-Jun-94	08:15:00 PM	1204.5	1124.9	90.09	86.09	20.03	1724.38	1551.94
TKEL15									
COLUMN TOTALS			**1,205**	**1,125**	**1,059**	**867**	**- NA -**	**17,351**	**15,616**

System Performance indicies	
Logging time/total hrs from RF star	**87.96%**
RF OUT/total hrs from RF start	**72.01%**
Heating period/hrs from RF start	**93.39%**
RF OUT/heating period	**77.11%**

Impact of required repairs and weather on RF generation efficiency			
RF OUT/heating up to 5/12 (splice)	**52.41%**	Average RF generation rate (kW/hr)	**9.42**
RF OUT/heating up to 5/20 (cable)	**62.50%**	Average RF generation rate (kW/hr)	**11.73**
RF OUT/heating from 5/20 - 6/10	**94.54%**	Average RF generation rate (kW/hr)	**19.93**

APPENDIX C - Power Measurements

AC and RF Power plots

DRAFT NOTE: These are samples of the data base. The final report will have sections of these plots in 120 hours segments.

- Examples of 3-phase AC input power to the system - before splice repair and cable replacement.

  5 May 03:10, 39.5 hrs

  (unit is also being held off to control temperature, black area at time 27.6 was due to autorestart attempts.

  6 May 19:42, 134 hrs

- Examples of 3-phase AC input power after line repair and replacement

  20 May 18:33, 48 hrs

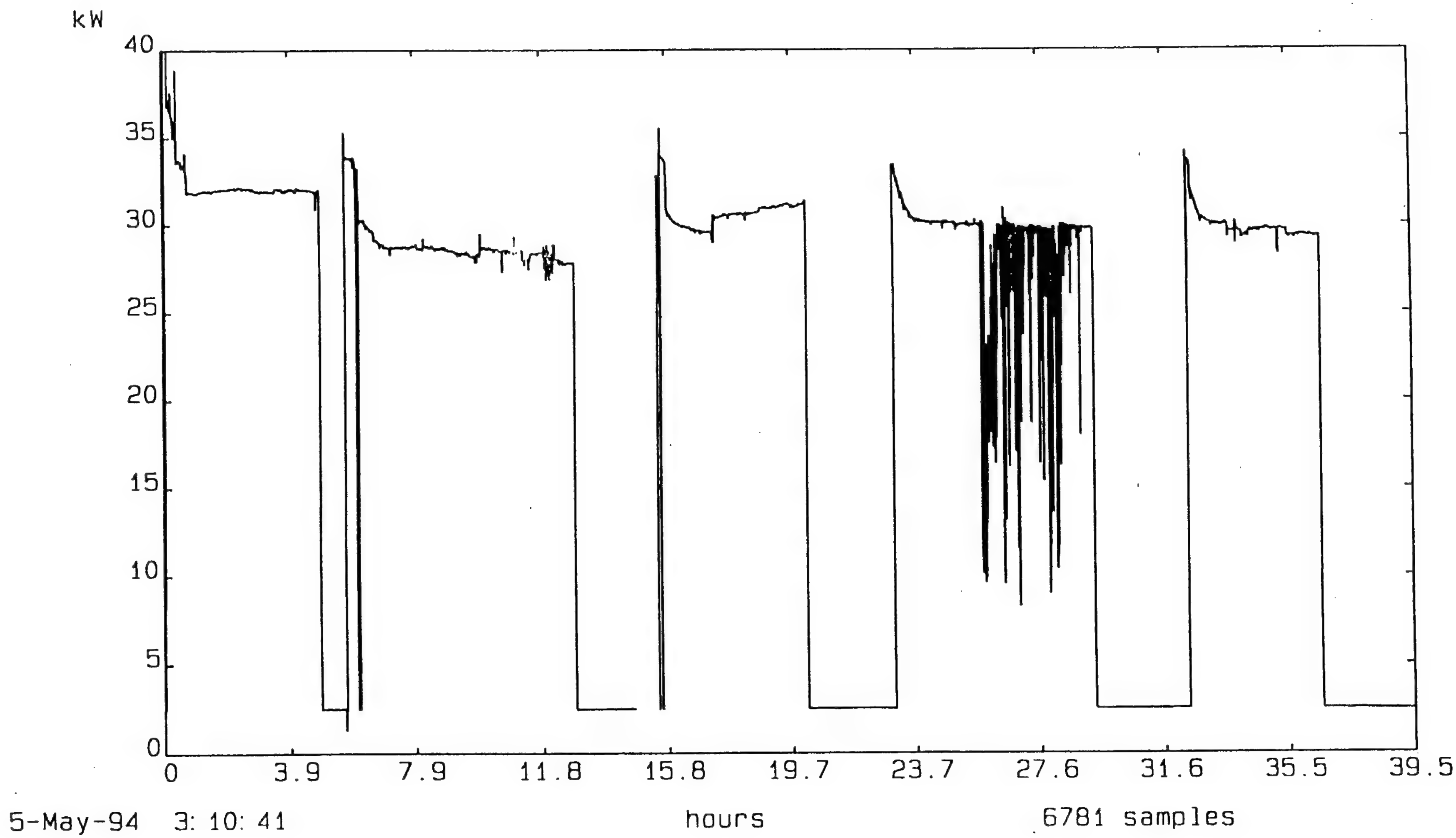
  (the broad break at 24 hours was used to make temperature profile measurements.

  04 June 00:24, 13 hrs

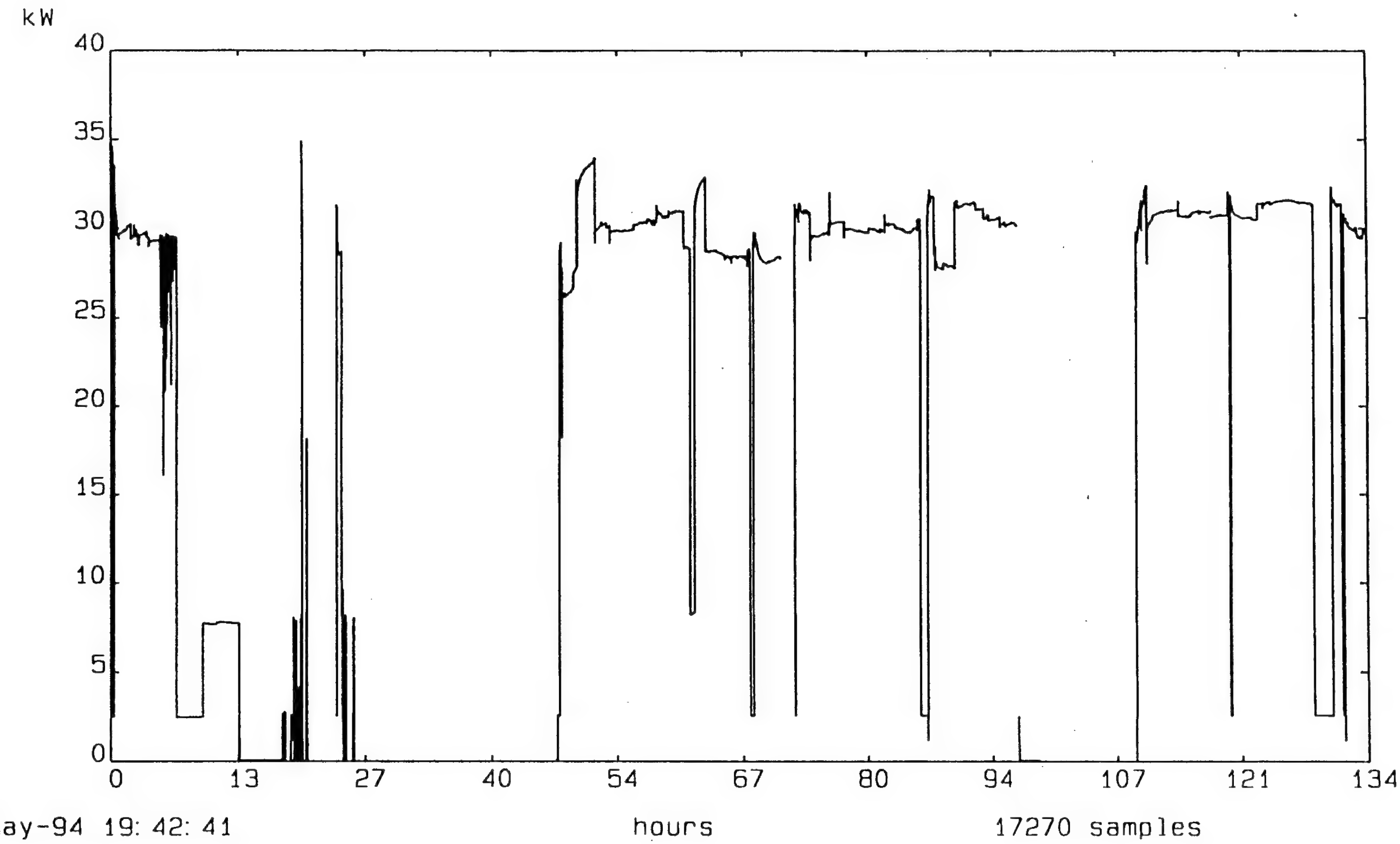
- Examples of RF generator power output

01-May	22:39,	71.9 hrs
20-May	18:33,	96.8 hrs
24 May	21:27,	96.8 hrs

END FILE: KELLYC.A

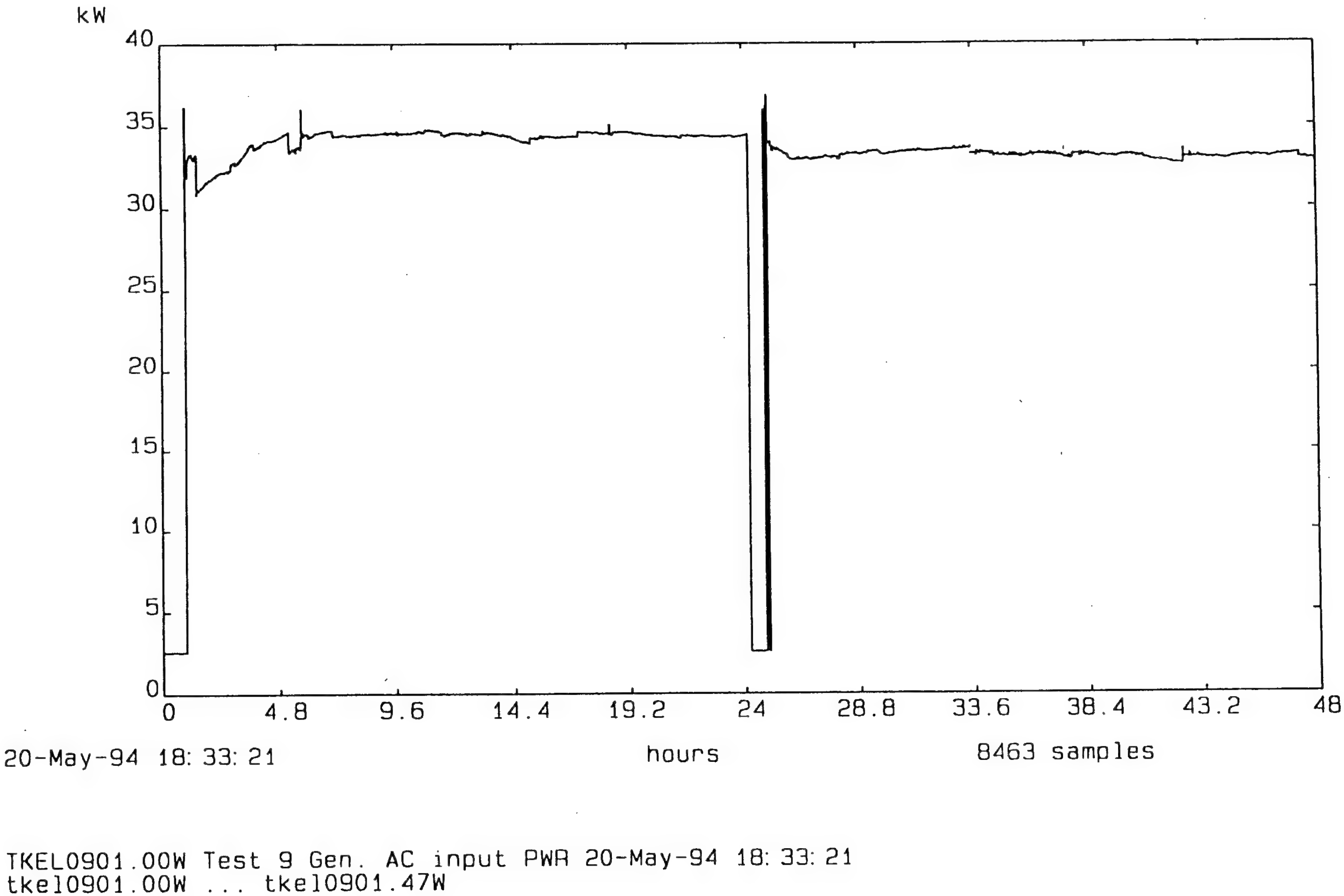


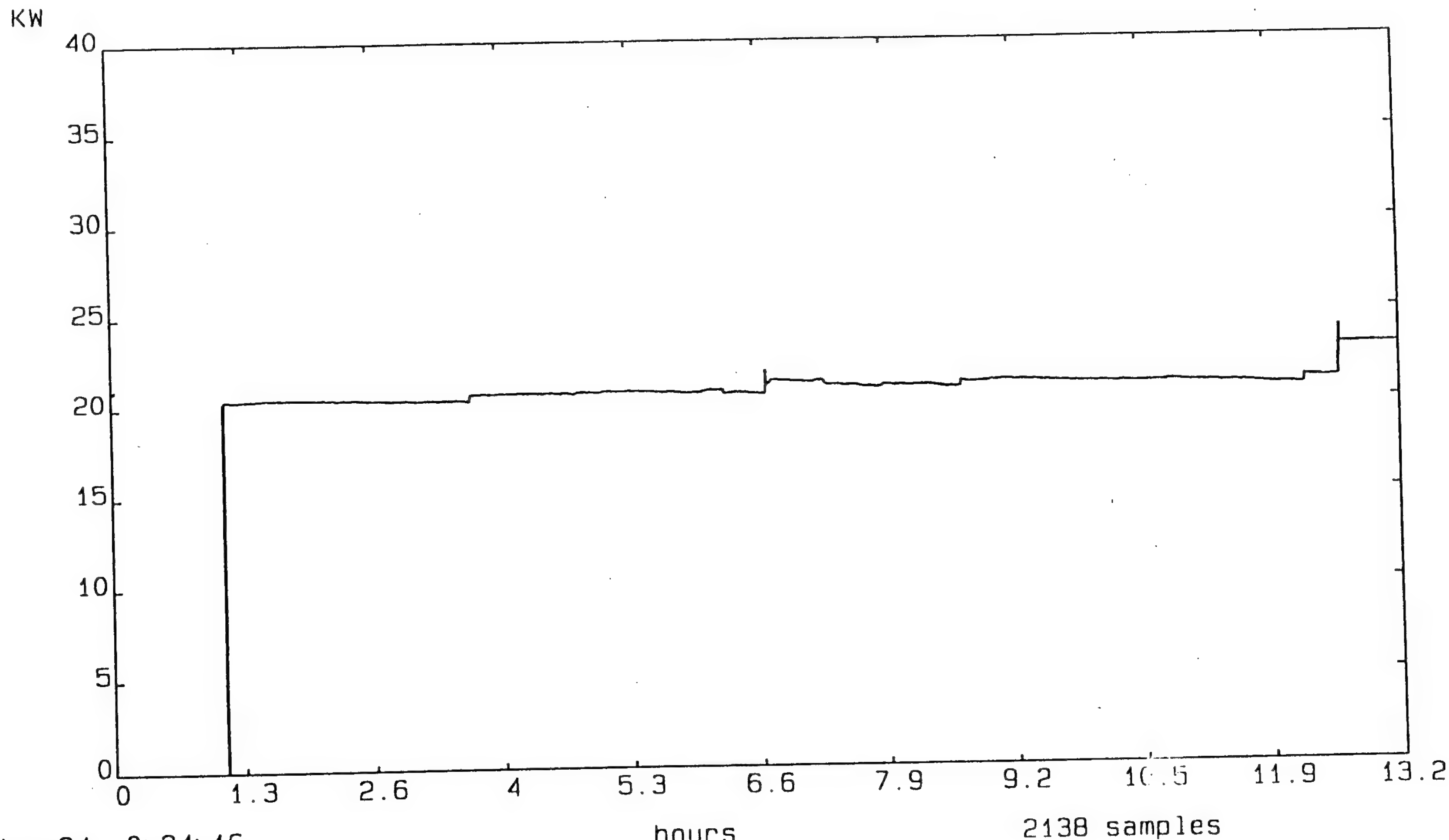
TKEL0501.01W Test 5 Gen. AC input PWR 5-May-94 3: 10: 41
tkel0501.01w ... tkel0501.39W



TKEL0601.01W Test 6 Gen. AC input PWR 6-May-94 19: 42: 41
tkel0601.01W ... tkel0601.99W

13-May-94

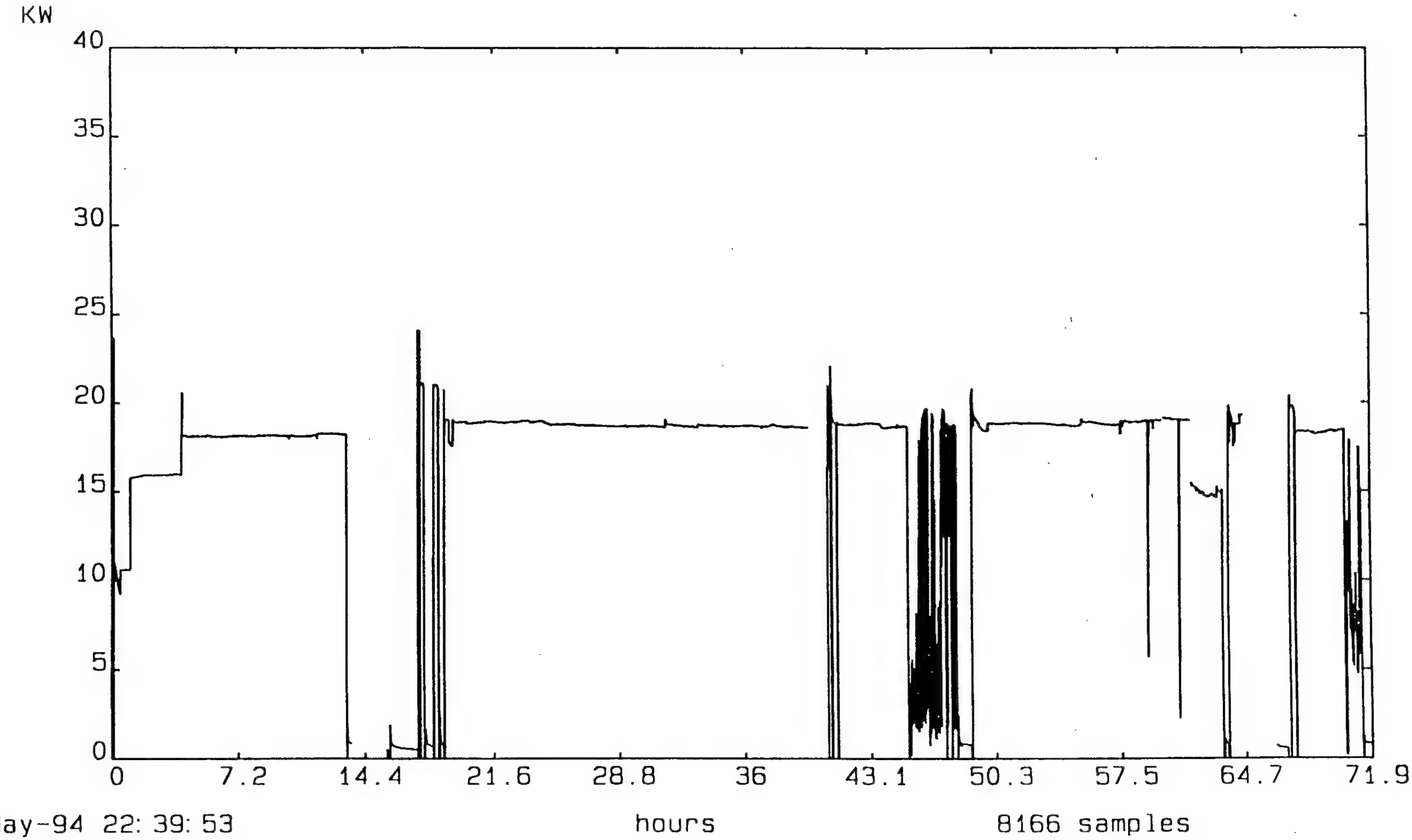

kW
40
35
30
25
20
15
10
5
0
0
4.8
9.6
14.4
19.2
24
28.8
33.6
38.4
43.2
48
20-May-94 18:33:21
hours
8463 samples
TKEL0901.00W Test 9 Gen. AC input PWR 20-May-94 18:33:21
tkel0901.00W ... tkel0901.47W



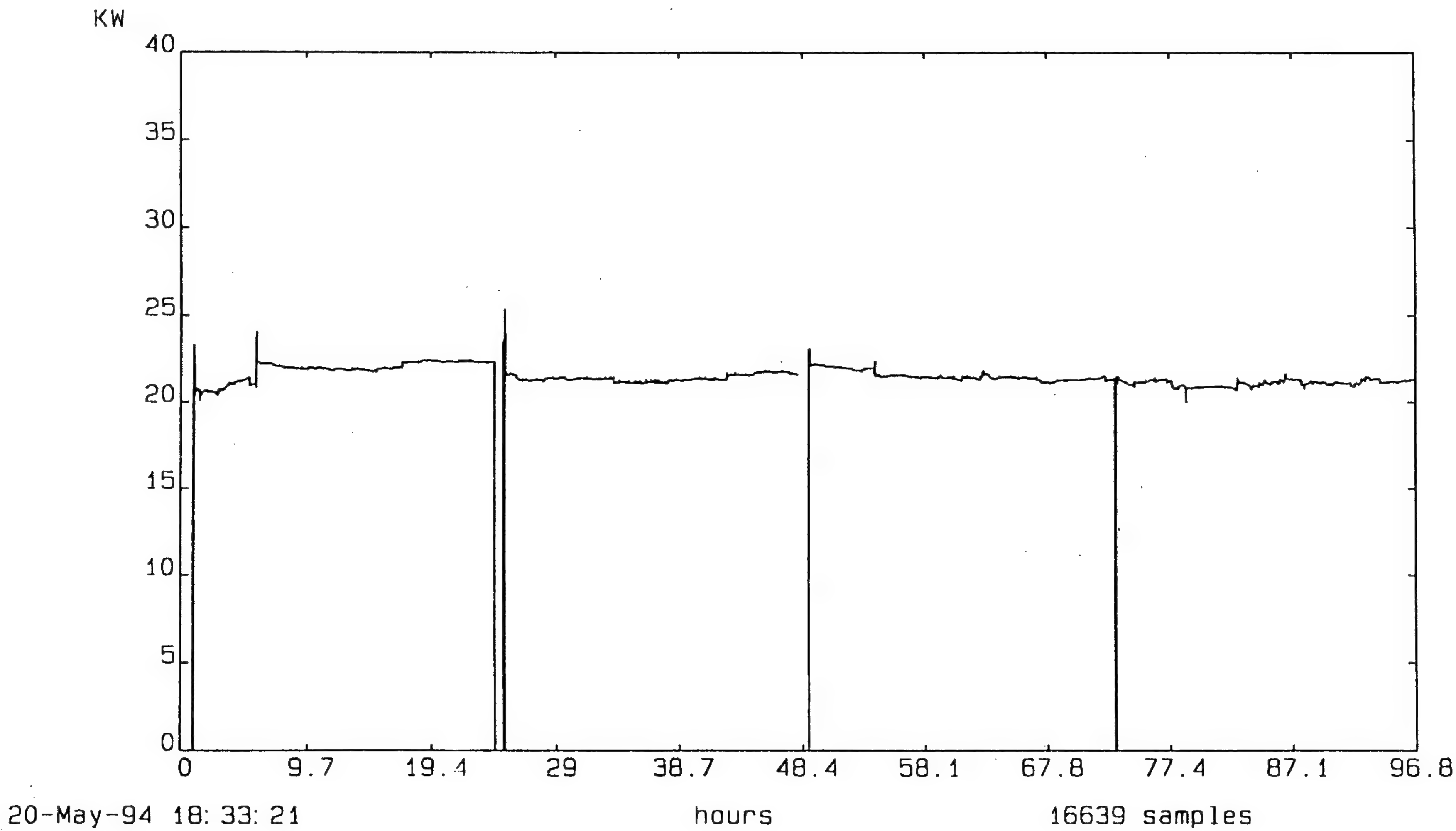
4-Jun-94 0: 24: 16

TKEL1302.00W Test 13 Gen. RF PWR Incident 4-Jun-94 0: 24: 16
tkeL1302.00W ... tkeL1302.12W

4-Jun-94

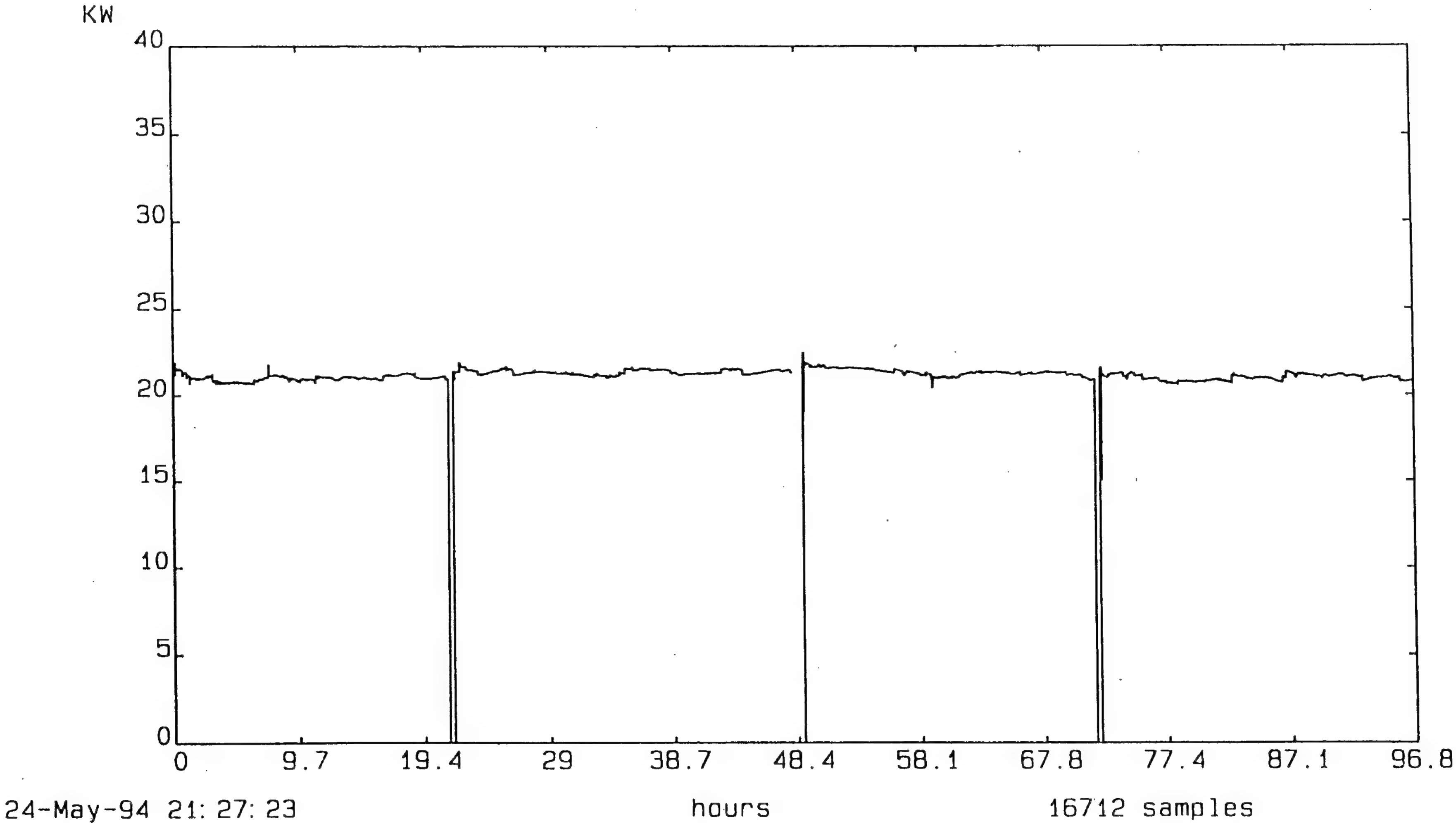


TKEL0402.01W Test 4 Gen. RF PWR Incident 1-May-94 22:39:53
tkel0402.01w ... tkel0402.47w



TKEL0902.00W Test 9 Gen. RF PWR Incident 20-May-94 18:33:21
tkel0902.00W ... tkel0902.93W

25-May-94



TKEL1002.00W Test 10 Gen. RF PWR Incident 24-May-94 21: 27: 23
tkel1002.00W ... tkel1002.92W

APPENDIX D - Temperature Plots Using Fiber Optics

Fiber optic probe measurements

The fiber optic temperature measurement we recorded by the data logging system as channels 21, 22, 23 or 24.

- Channel 21 - outside wall temperature of well liner A2 at a depth of 10.5 ft.

21 April 1994, 15:44, Day 8.65 -	50 hour plot
24 April 1994, 23:19, Day 11.97 -	120 hour plot
01 May 1994, 22:39, Day 18.94 -	120 hour plot
06 May 1994, 23.82, Day 23.82 -	120 hour plot

- Selected plot of channel 21 - applicator #1

19 May 1994, 15:50, Day ____ -	25 hour plot, peak temperature reading for program
20 May 1994, 18:33, Day ____-	96.8 hour plot
24 May 1994, 21:27, Day ____-	96.8 hour plot

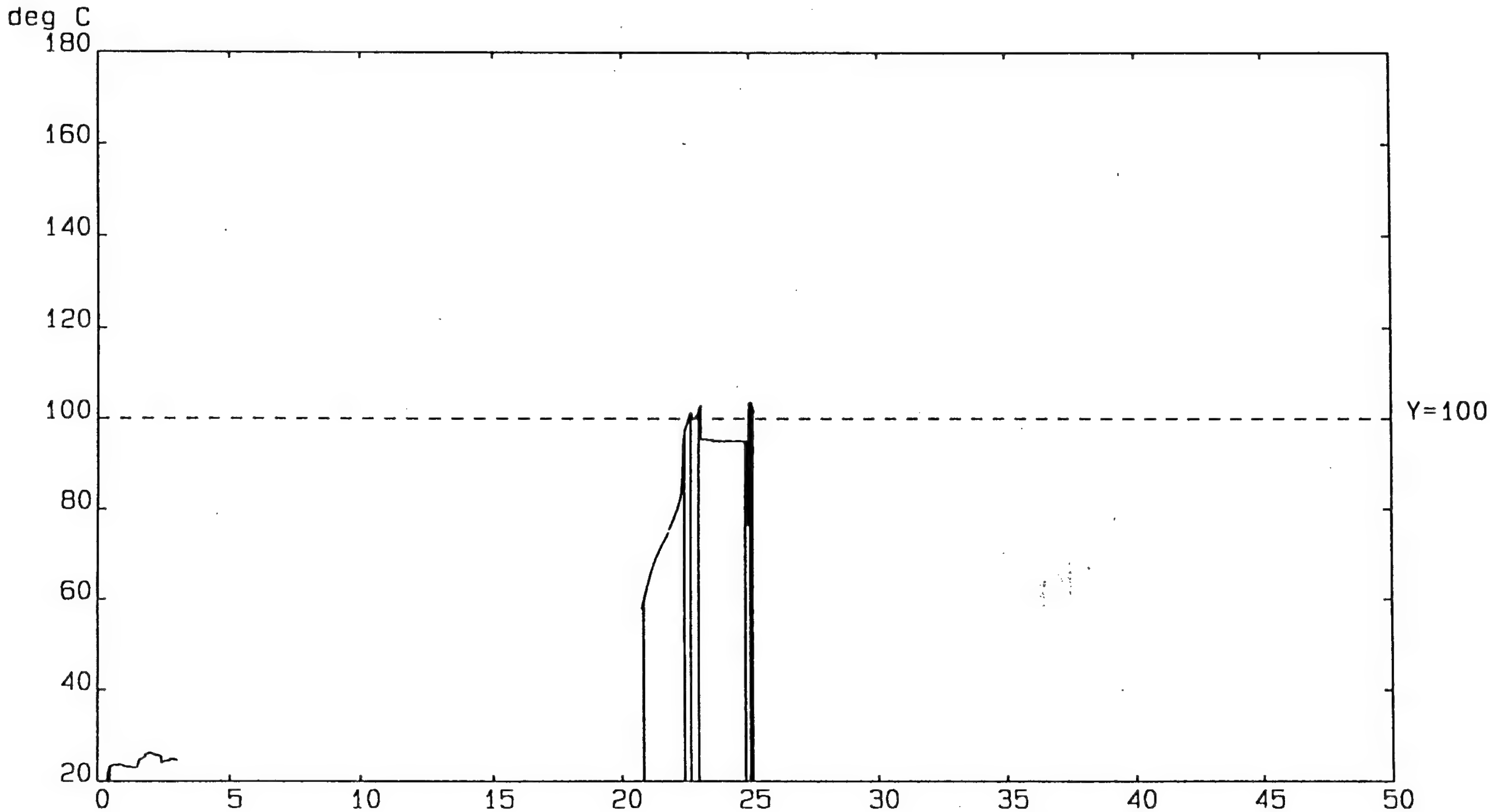
- Selected plot of channel 22 - applicator #2

20 May 1994, 18:33, Day_____-	96.8 hour plot
24 May 1994, 21:27, Day_____-	96.8 hour plot
28 May 1994, 23:22, Day_____-	39.9 hour plot

DRAFT NOTE: The above and others to be provided in 120 hour plot format for final report.

END FILE: KELLYD.A

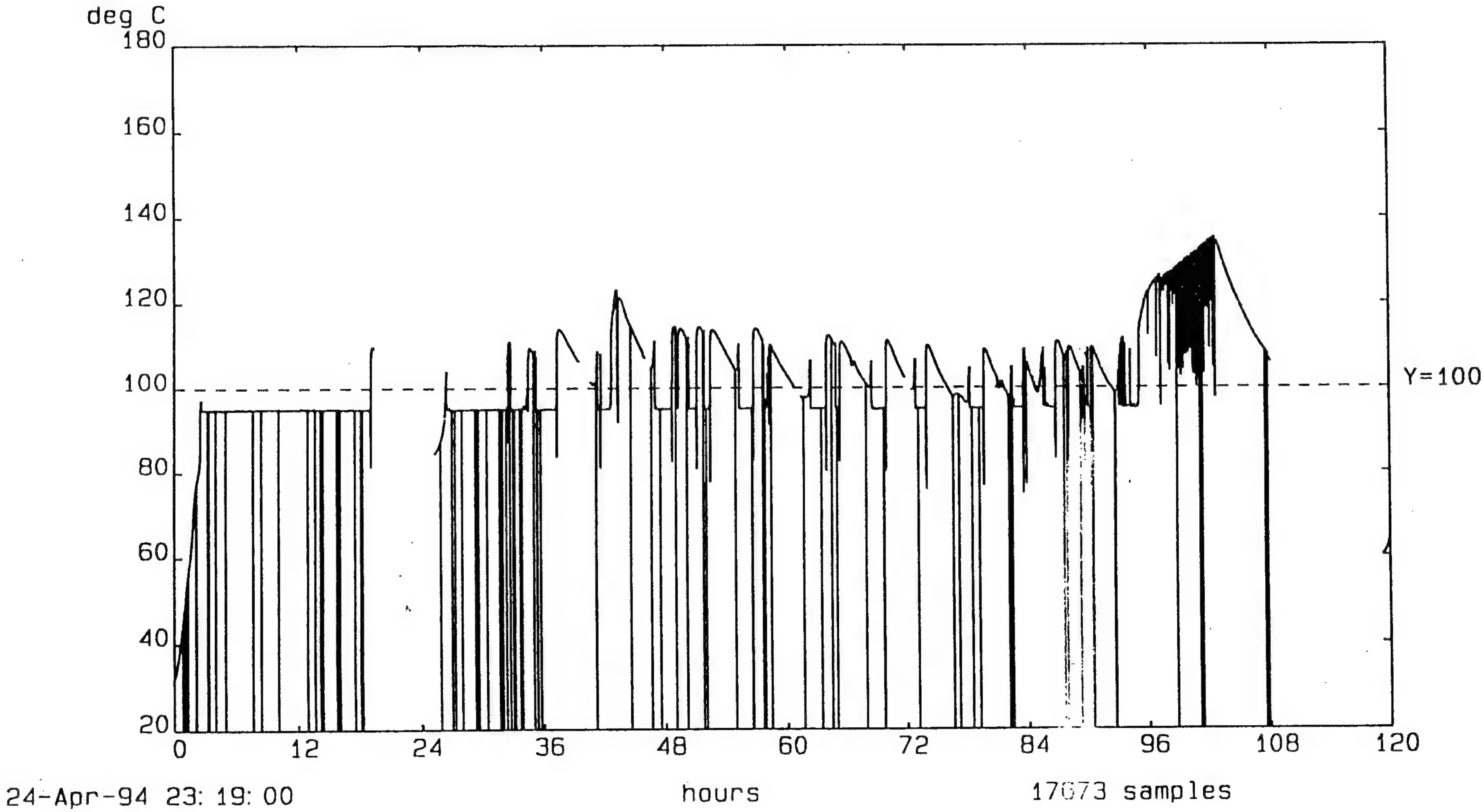
Preheat EMI test period - Start: Day 8.65



21-Apr-94 15: 44: 44 hours 1572 samples

Tkel0021.01C Emissions test LUX 1 - APP#1 WALL @ 9.5' 21-Apr-94 15: 44: 44
tkel0021.01c ... tkel0221.06c

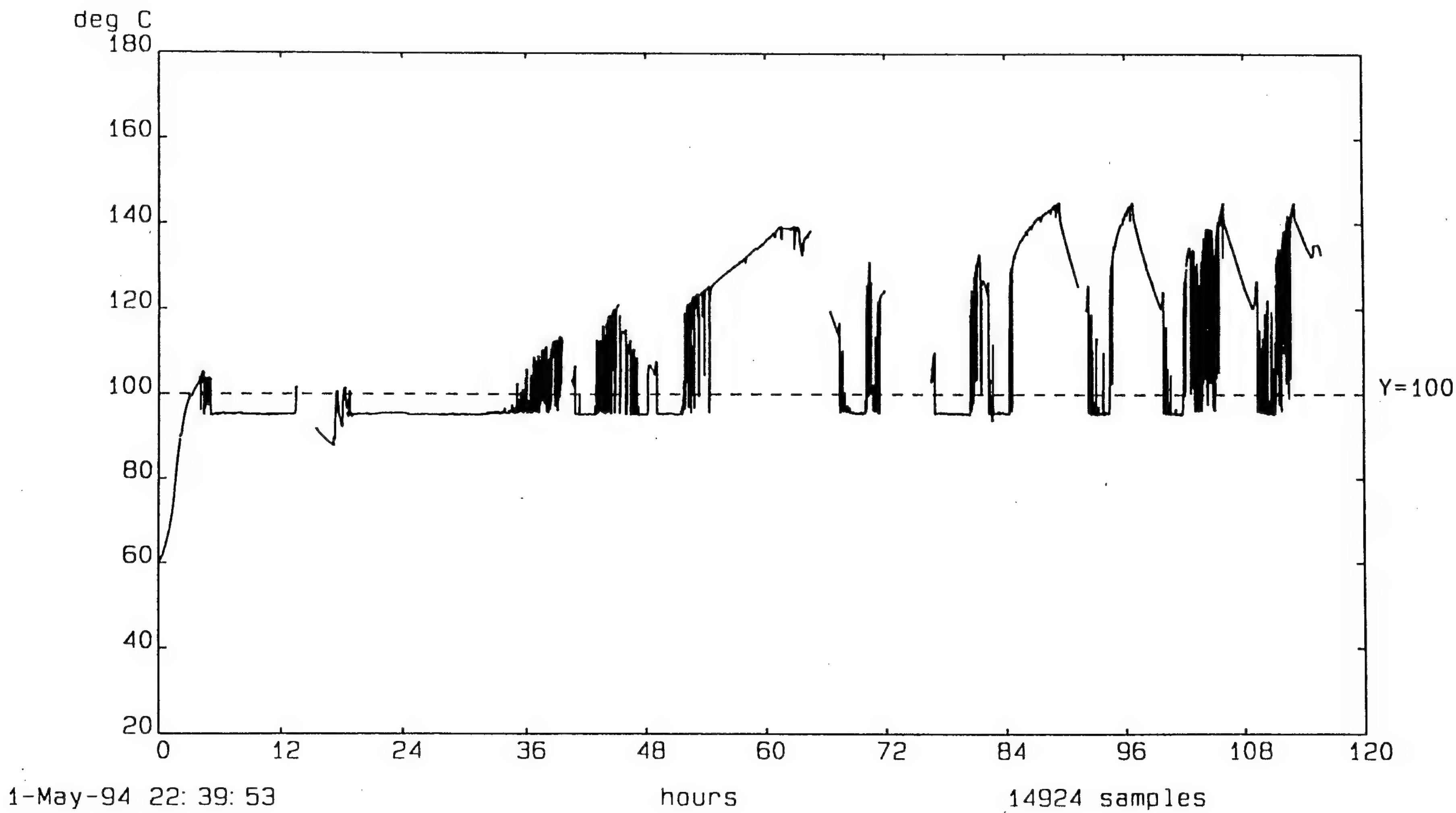
Start of Applicator #1 heating period - Start: Day 11.97



Tkel0321.01C EM test 3 APP#1 WALL @10.5' 24-Apr-94 23: 19: 00
tkel0321.01C ... tkel0421.15c

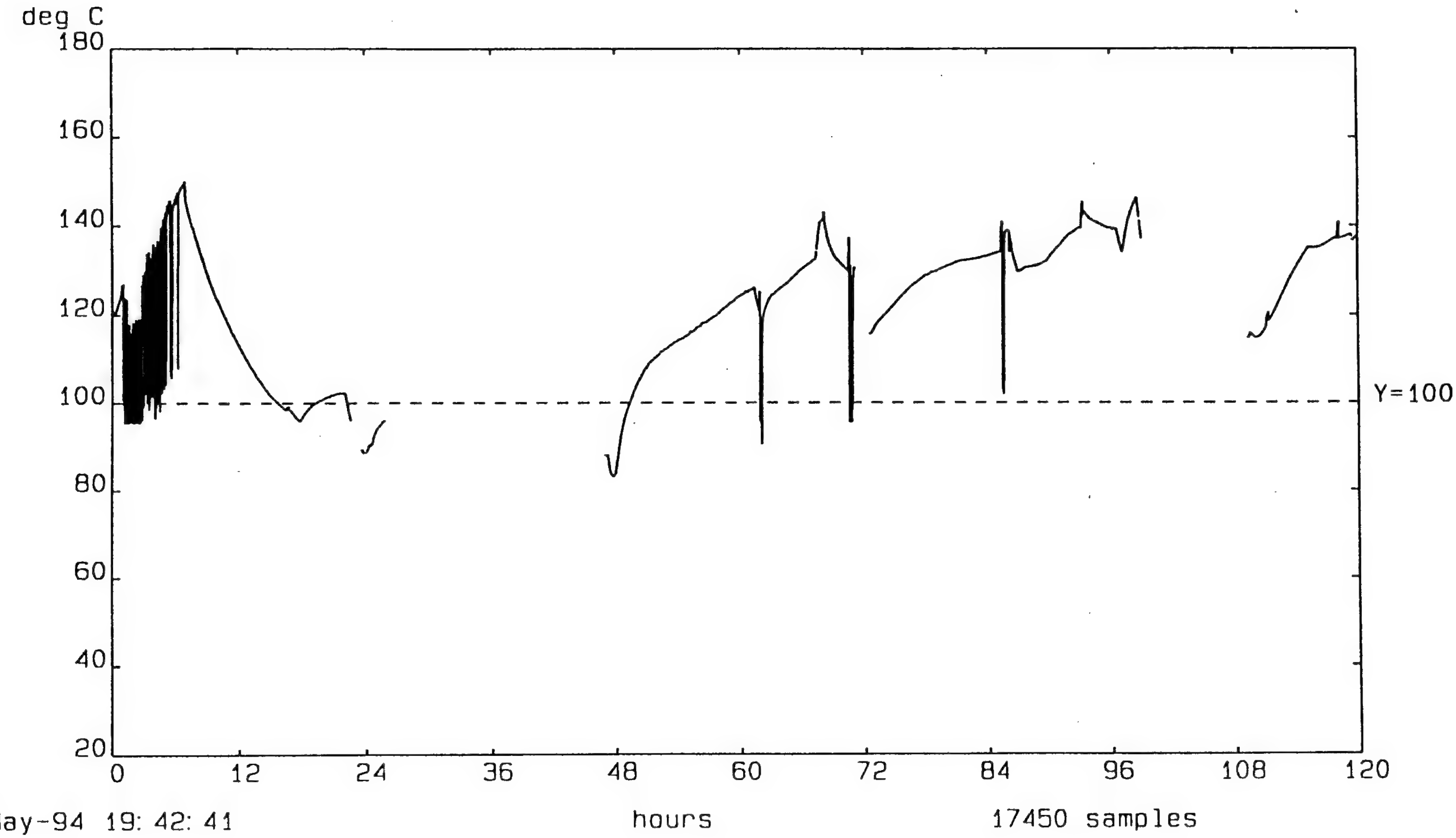
31-Oct-94

Continuation of Applicator #1 heating period - Start: Day 18.94



TKEL0421.01C Test 4 APP#1 WALL @10.5'(s) 1-May-94 22: 39: 53
tkel0421.01c ... tkel0521.38C

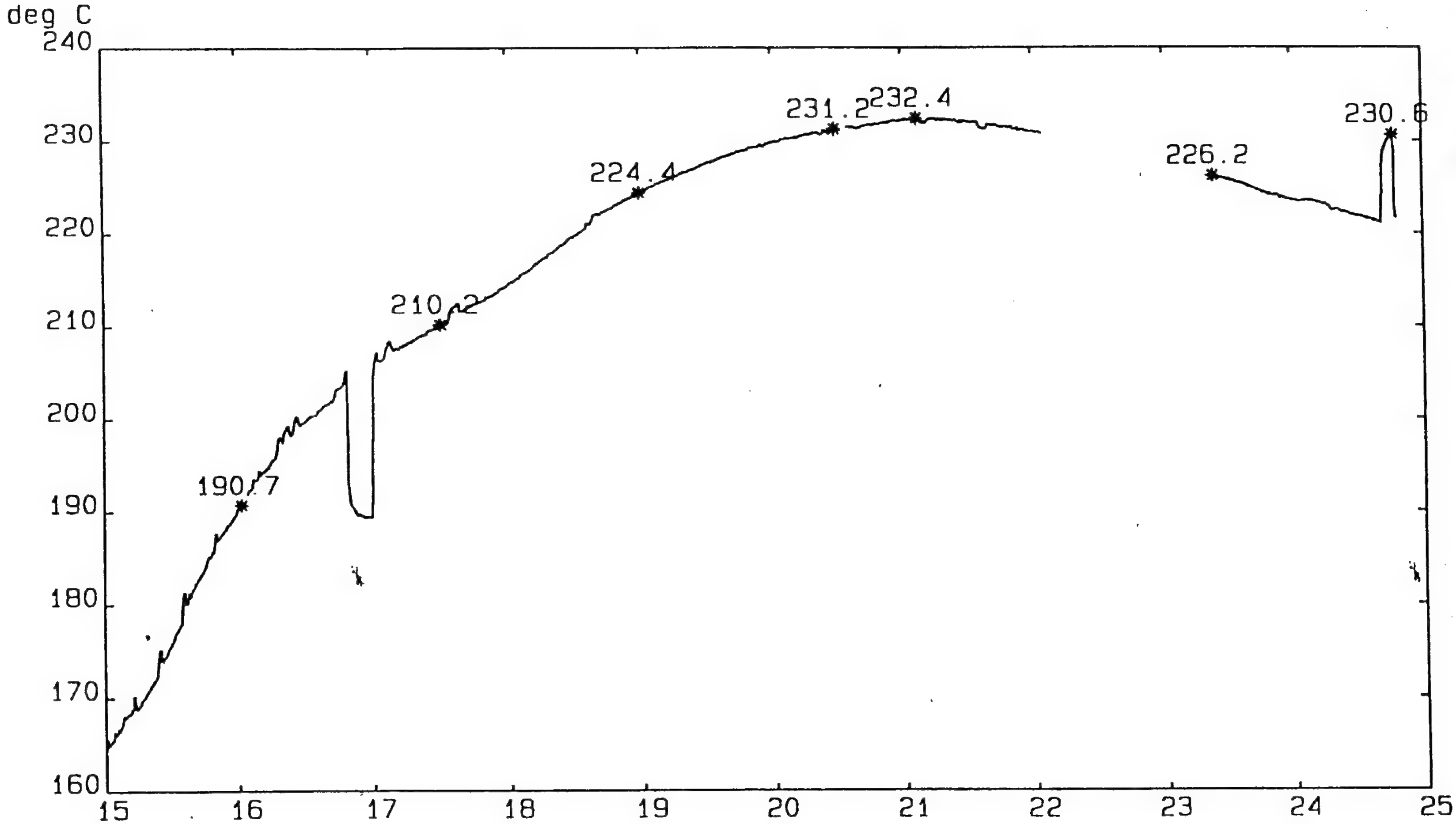
Start of Applicator #1 heating period - Start: Day 23.82



TKEL0621.01C Test 6 APP#1 WALL @10.5'(s) 6-May-94 19: 42: 41
tkel0621.01C ... tkel0721.01C

31-Oct-94

Applicator A1 - outside wall sleeve temperature by fiber optic probe (add 1.5 deg)



19-May-94 15: 50: 42 hours 1695 samples

TKEL0821.80C Test 8 APP#1 WALL @10.5'(s) 19-May-94 15: 50: 42
tkel0821.80c ... tkel0921.02c

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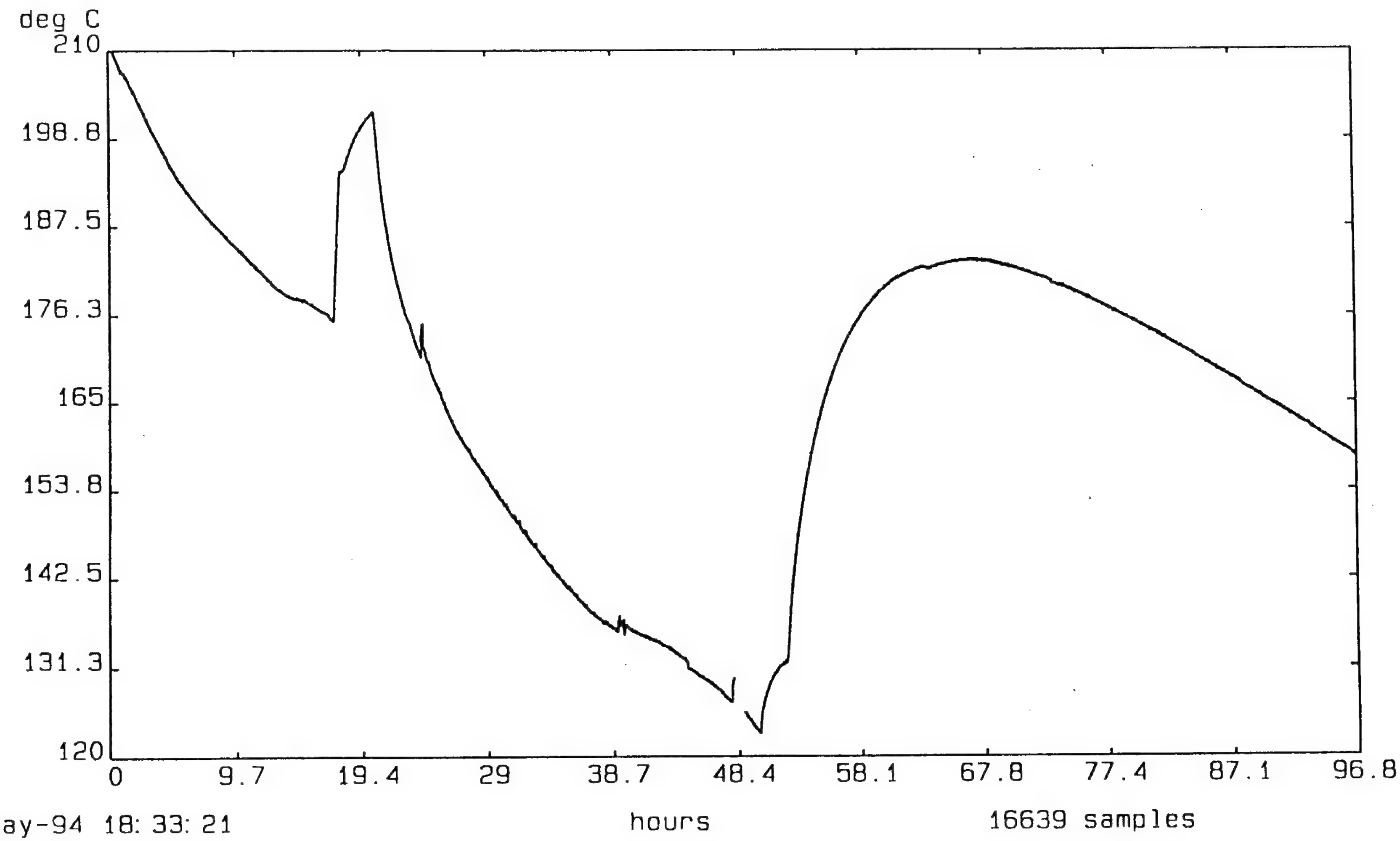
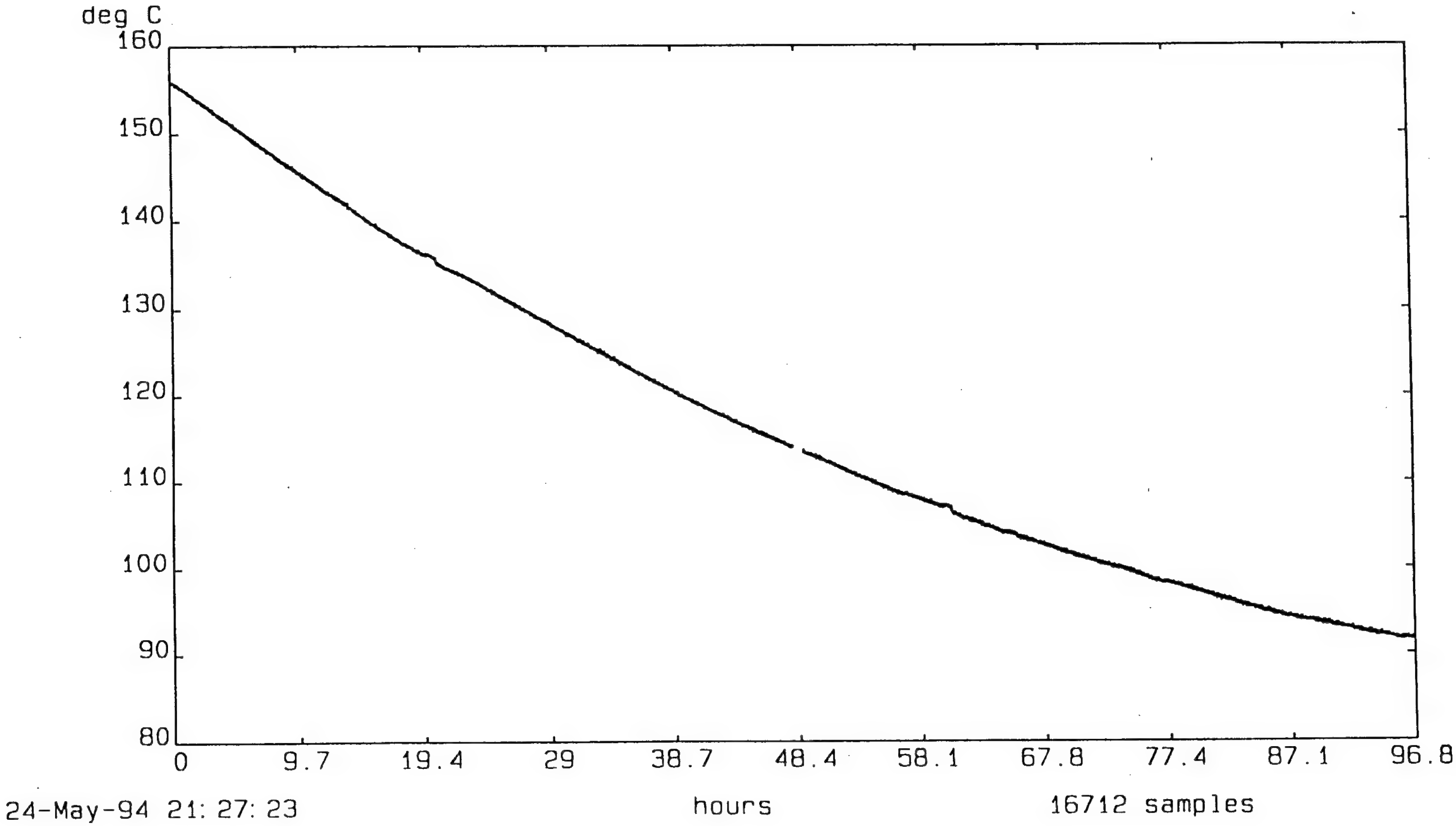
25-Oct-94



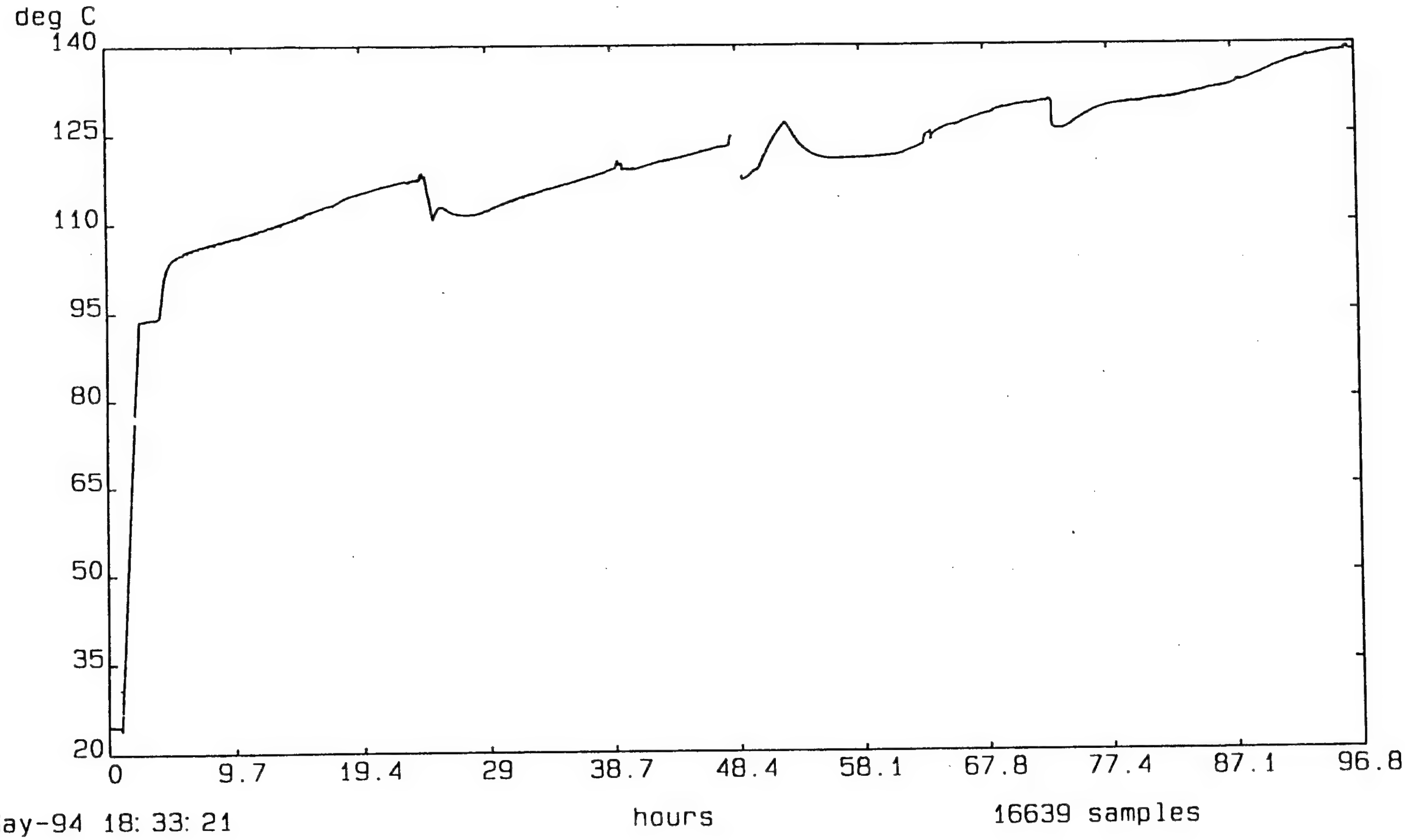
TKEL0921.00C Test 9 APP#1 WALL @10.5'(s) 20-May-94 18:33:21
tkel0921.00C ... tkel0921.93C

25-May-94



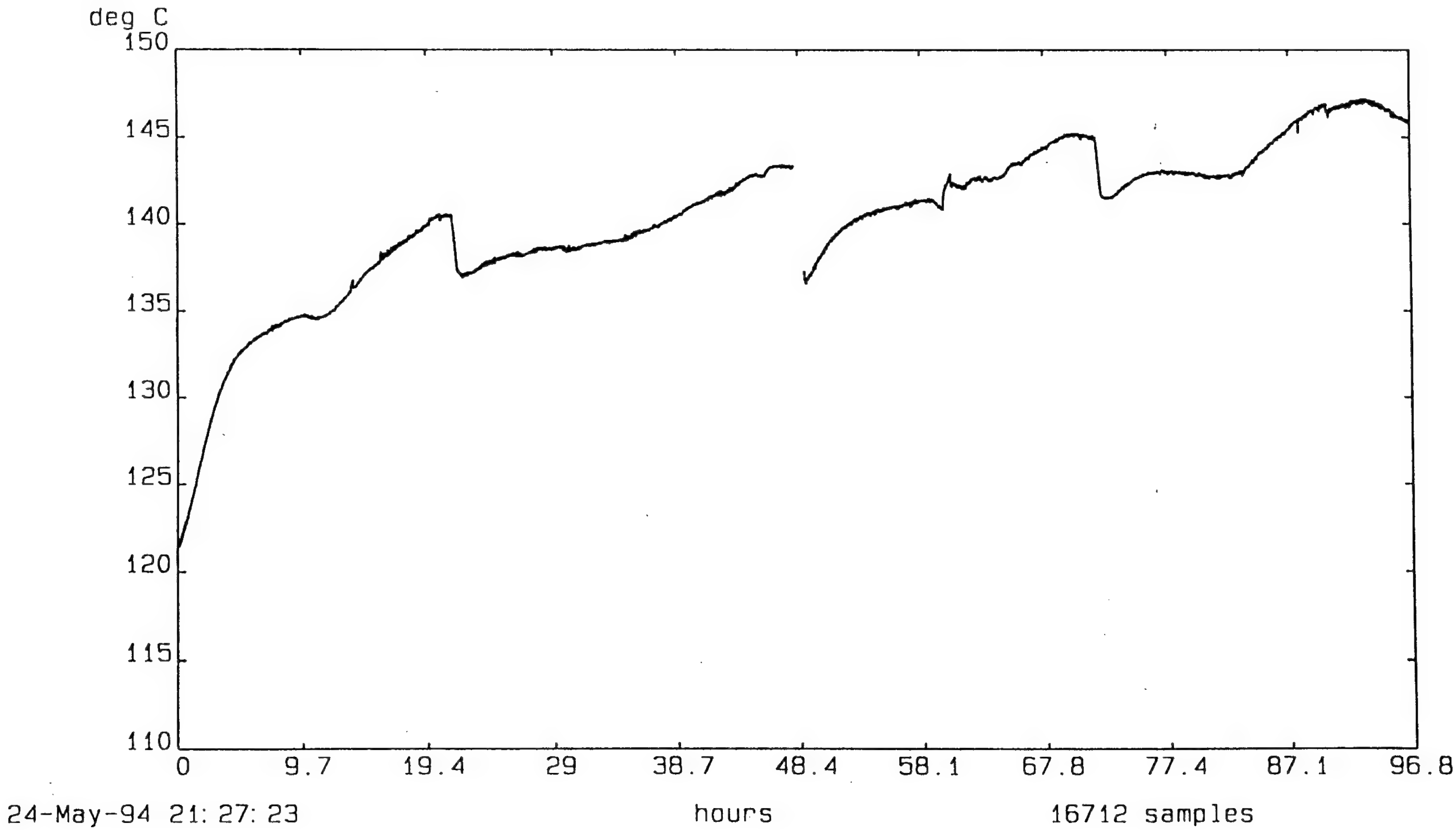
TKEL1021.00C Test 10 APP#1 WALL @10.5'(s) 24-May-94 21:27:23
tkel1021.00C ... tkel1021.92C

30-May-94



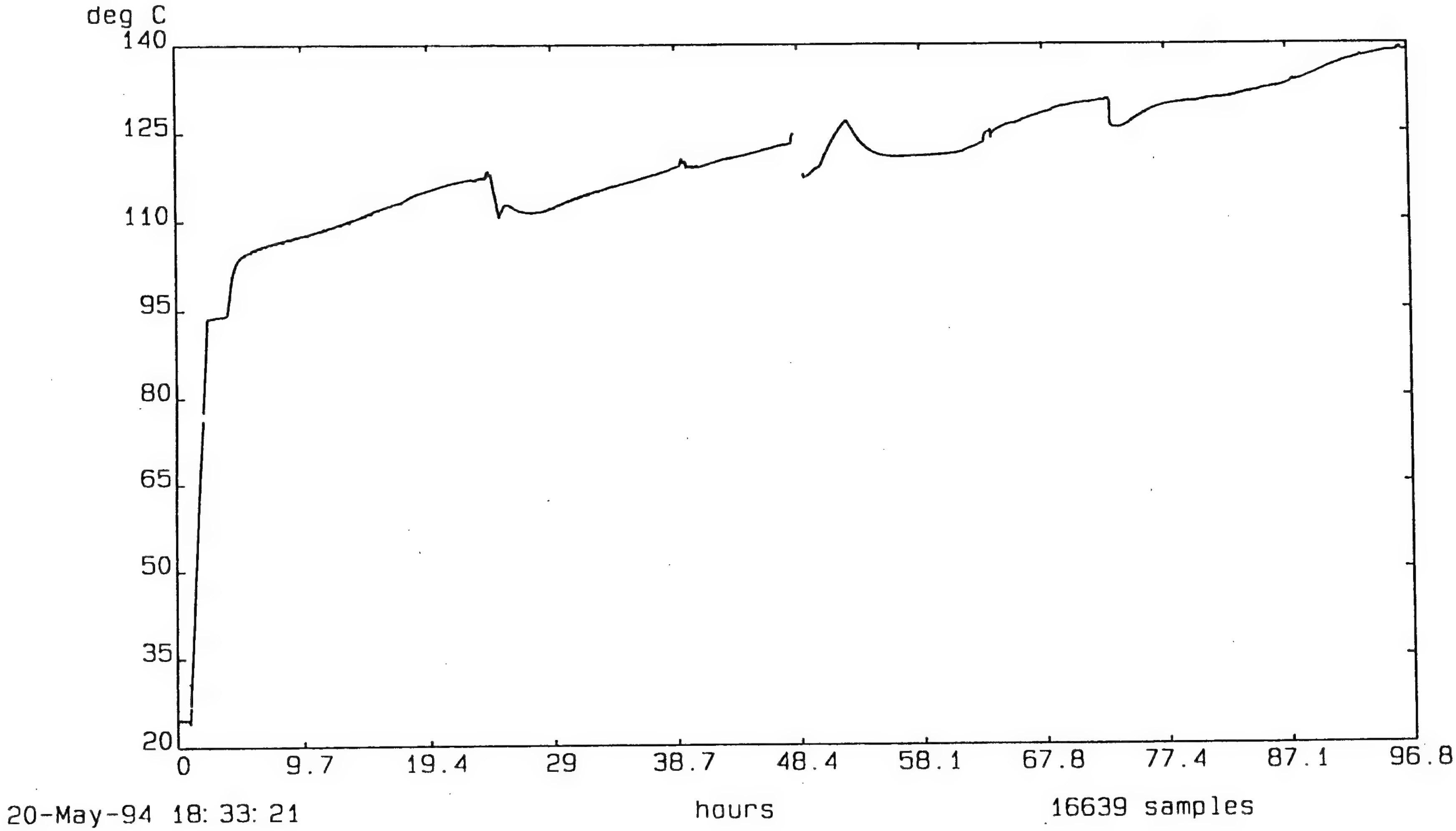
TKEL0922.00C Test 9 APP#2 WALL @10.5' ( ) 20-May-94 18:33:21
tkel0922.00C ... tkel0922.93C

25-May-94



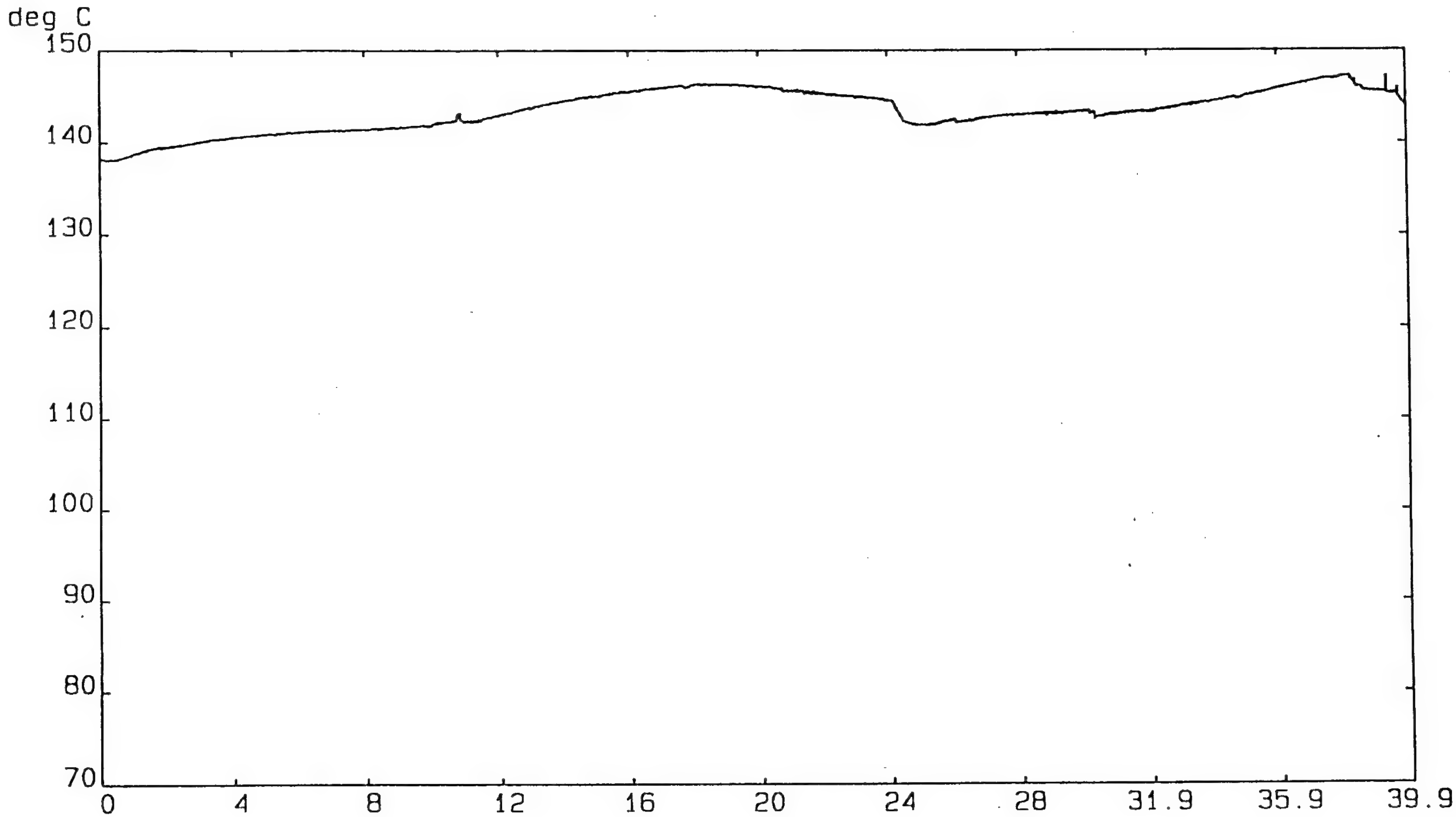
TKEL1022.00C Test 10 APP#2 WALL @10.5' ( ) 24-May-94 21: 27: 23
tkel1022.00C ... tkel1022.92C

30 -94



TKEL0922.00C Test 9 APP#2 WALL @10.5' ( ) 20-May-94 18: 33: 21
tke10922.00C ... tke10922.93C

25-May-94



28-May-94 23:22:39 hours 6999 samples

TKEL1122.00C Test 11 APP#2 WALL @10.5'( ) 28-May-94 23:22:39
tkel1122.00C ... tkel1122.38C

3-Jun-94

APPENDIX E - Temperature Profiles Using Thermocouples

Thermocouple measurements

Plot TC-1 over a 7 to 77 day span - all depths
Plot TC-2 - all depths
Plot TC-3 - all depths

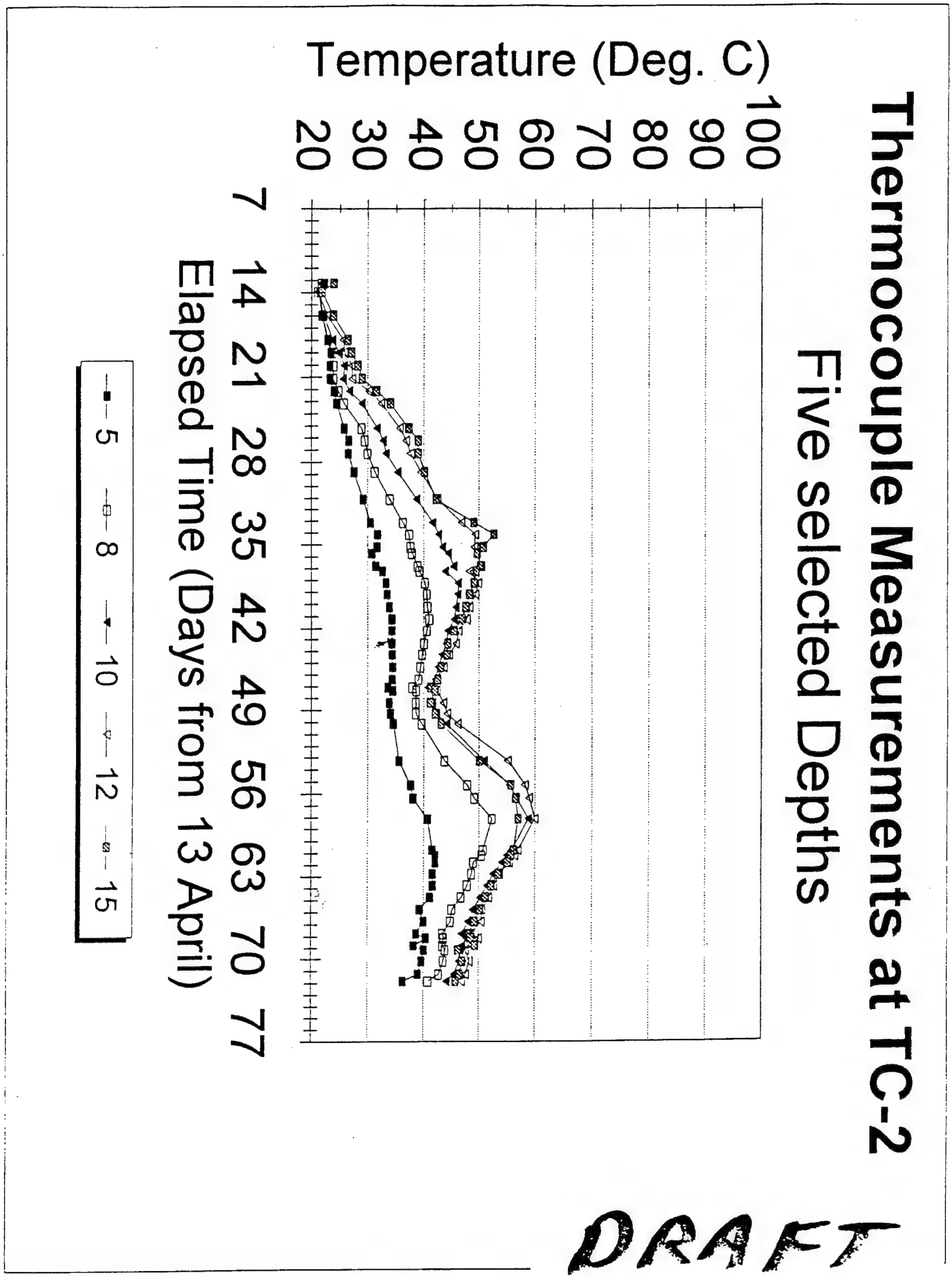
Plot TC-1 - at 5 depths
Plot TC-2 - at 5 depths
Plot TC-3 - at 5 depths

TC-1 Temperature profiles - 20 May to 24 May
TC-1 Temperature profiles - 24 May to 29 May
TC-1 Temperature profiles - 29 May to 02 June
TC-1 Temperature profiles - 02 June to 13 June
TC-1 Temperature profiles - 07 June to 14 June

TC-2 Temperature profiles - 20 May to 24 May
TC-2 Temperature profiles - 24 May to 29 May
TC-2 Temperature profiles - 29 May to 02 June
TC-2 Temperature profiles - 02 June to 13 June
TC-2 Temperature profiles - 07 June to 14 June

TC-3 Temperature profiles - 20 May to 24 May
TC-3 Temperature profiles - 24 May to 29 May
TC-3 Temperature profiles - 29 May to 02 June
TC-3 Temperature profiles - 02 June to 13 June
TC-3 Temperature profiles - 07 June to 14 June

END FILE: KELLYE.A



Thermocouple Measurements at TC-2
Five selected Depths
Temperature (Deg. C)
100
90
80
70
60
50
40
30
20
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
5
8
10
12
15

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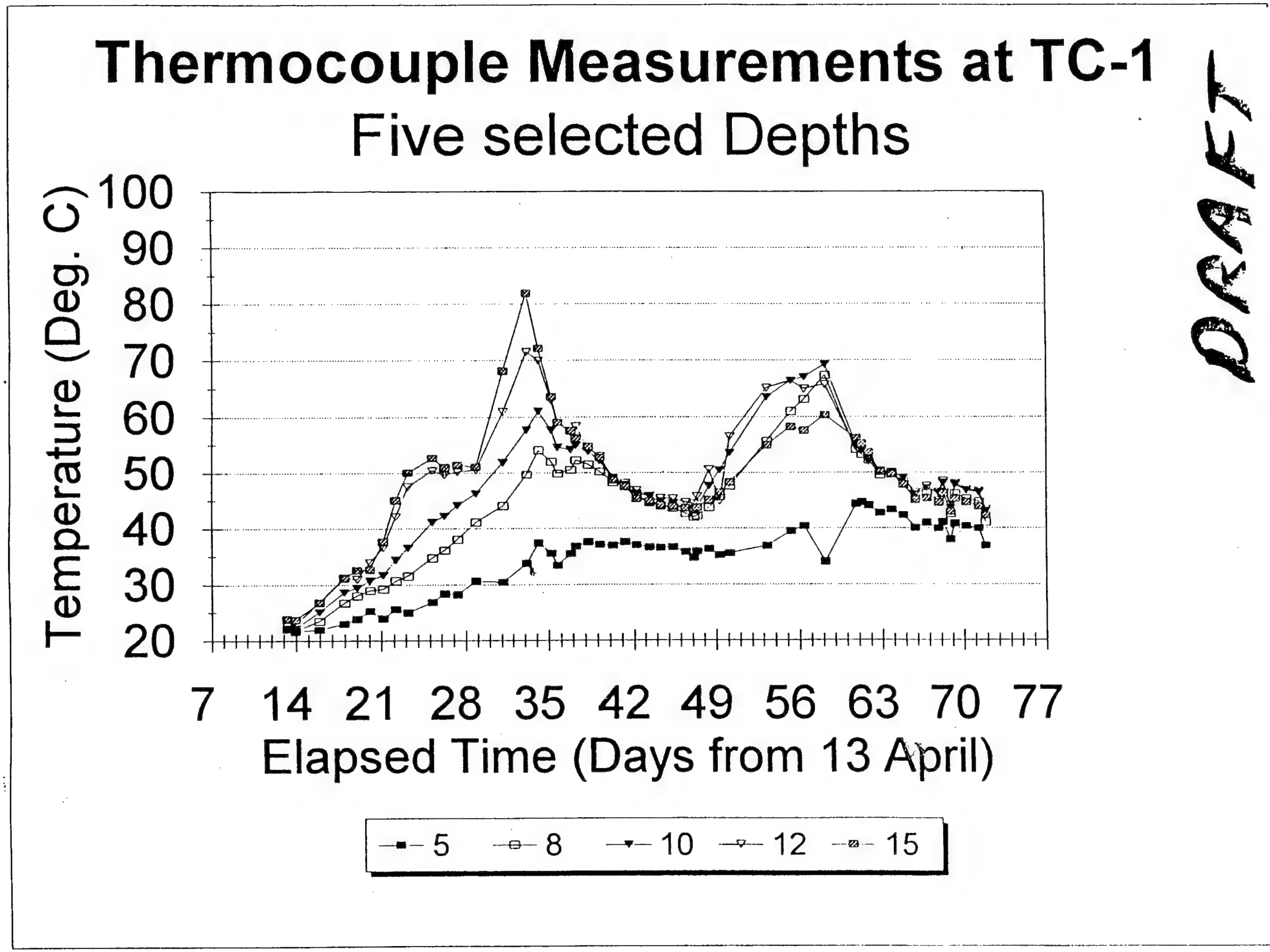

Thermocouple Measurements at TC-1
Five selected Depths
Temperature (Deg. C)
100
90
80
70
60
50
40
30
20
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
5
8
10
12
15

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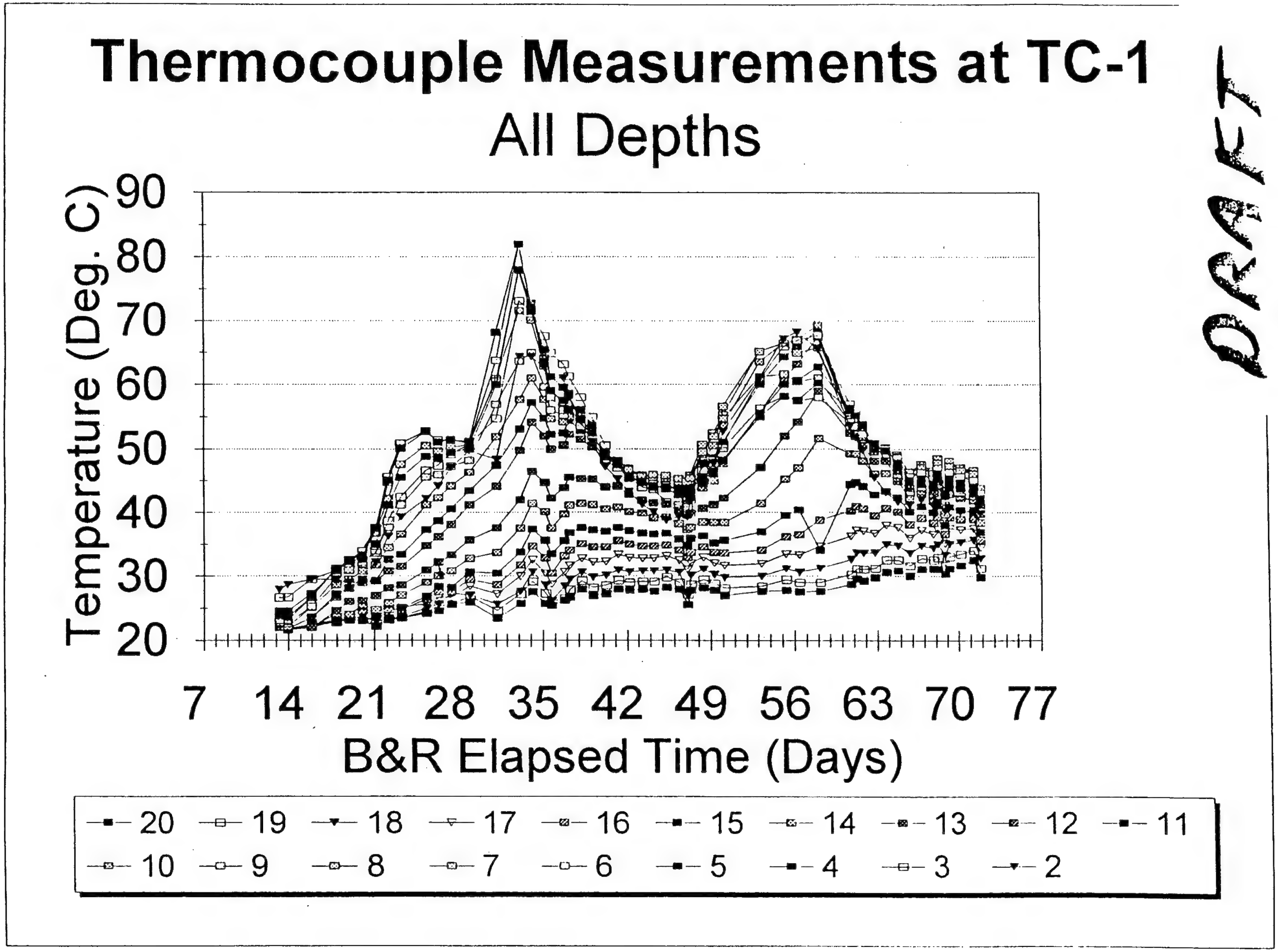

Thermocouple Measurements at TC-1
All Depths
Temperature (Deg. C)
90
80
70
60
50
40
30
20
7
14
21
28
35
42
49
56
63
70
77
B&R Elapsed Time (Days)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2

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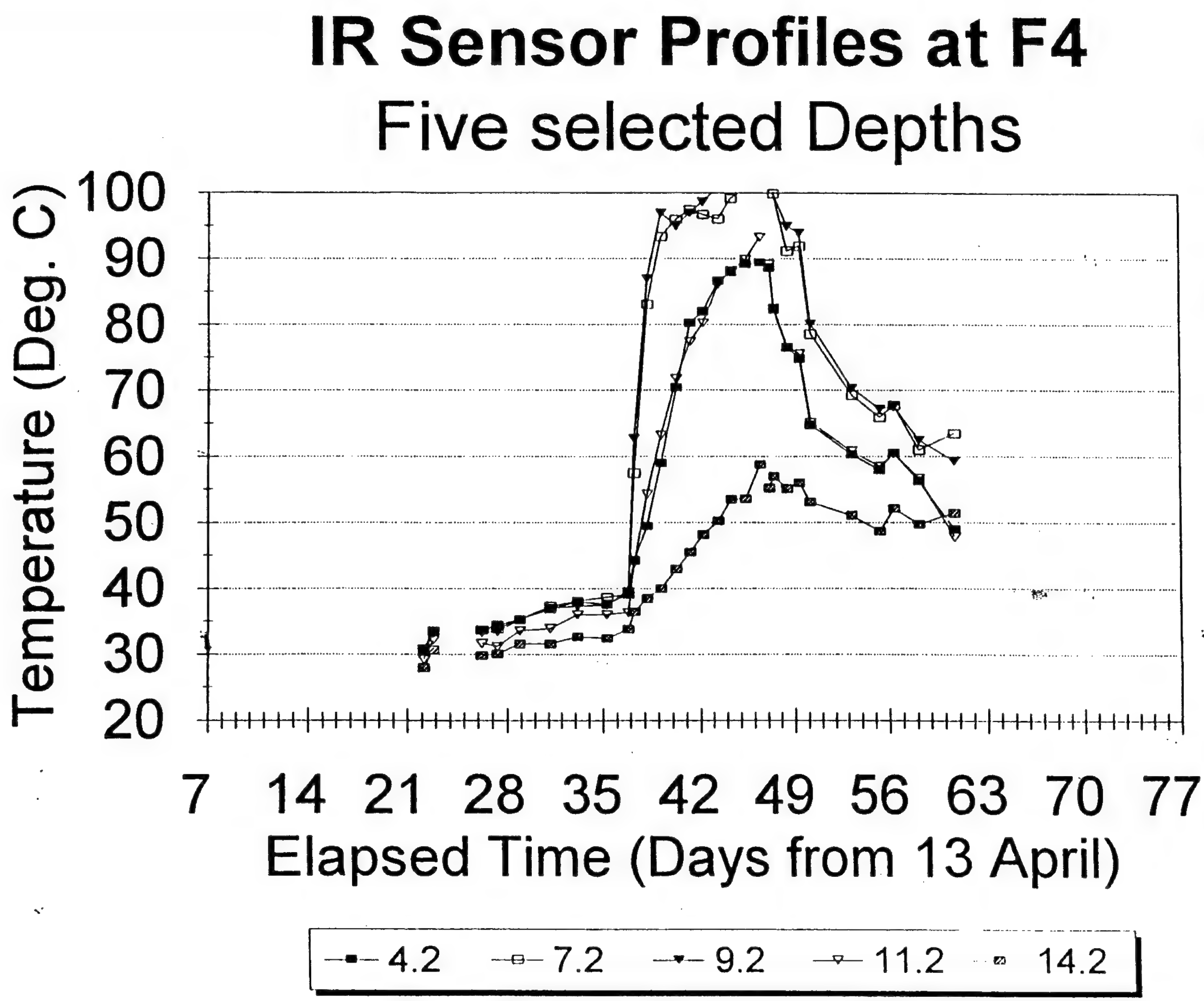
IR Sensor Profiles at F4
Five selected Depths
Temperature (Deg. C)
100
90
80
70
60
50
40
30
20
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
4.2
7.2
9.2
11.2
14.2

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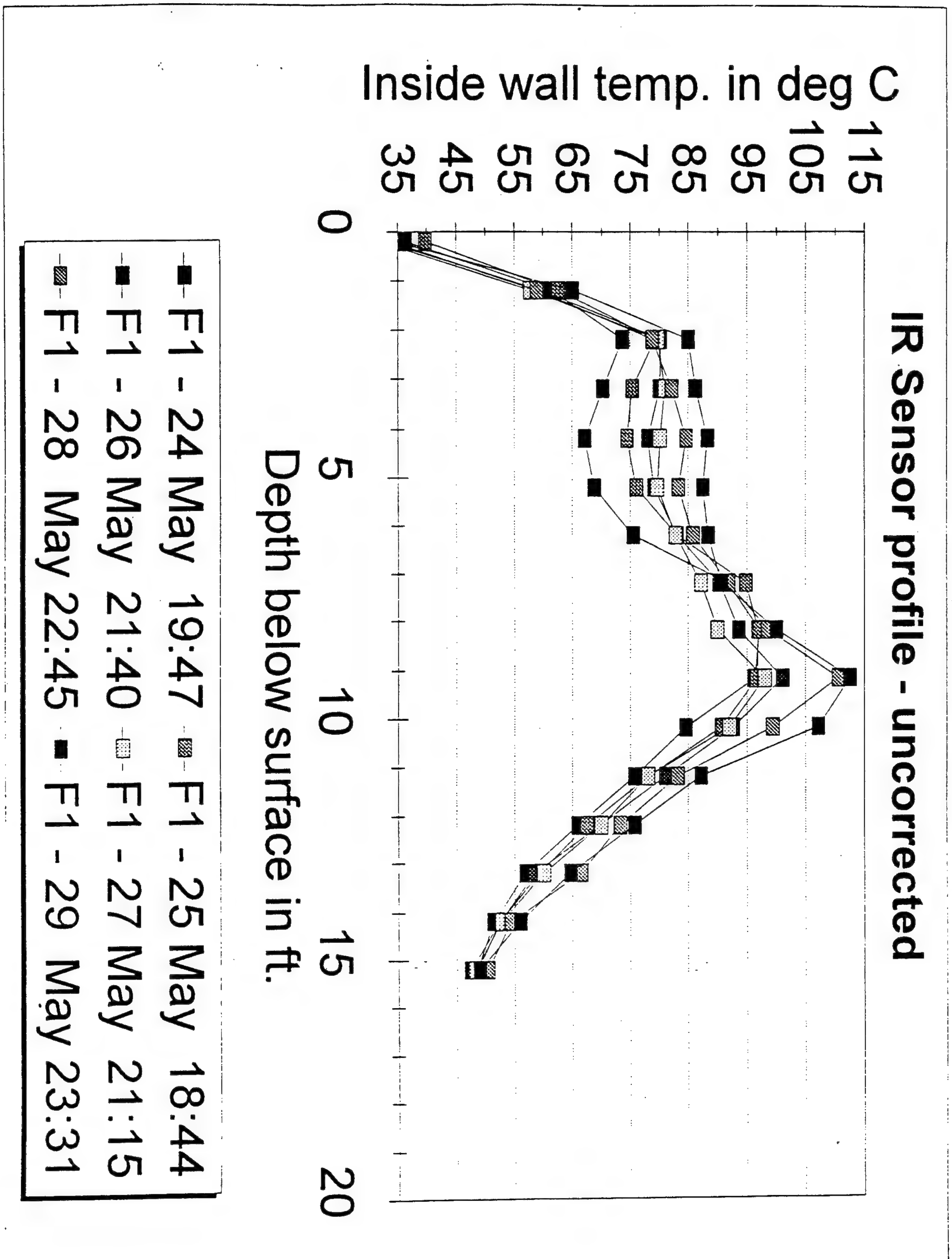
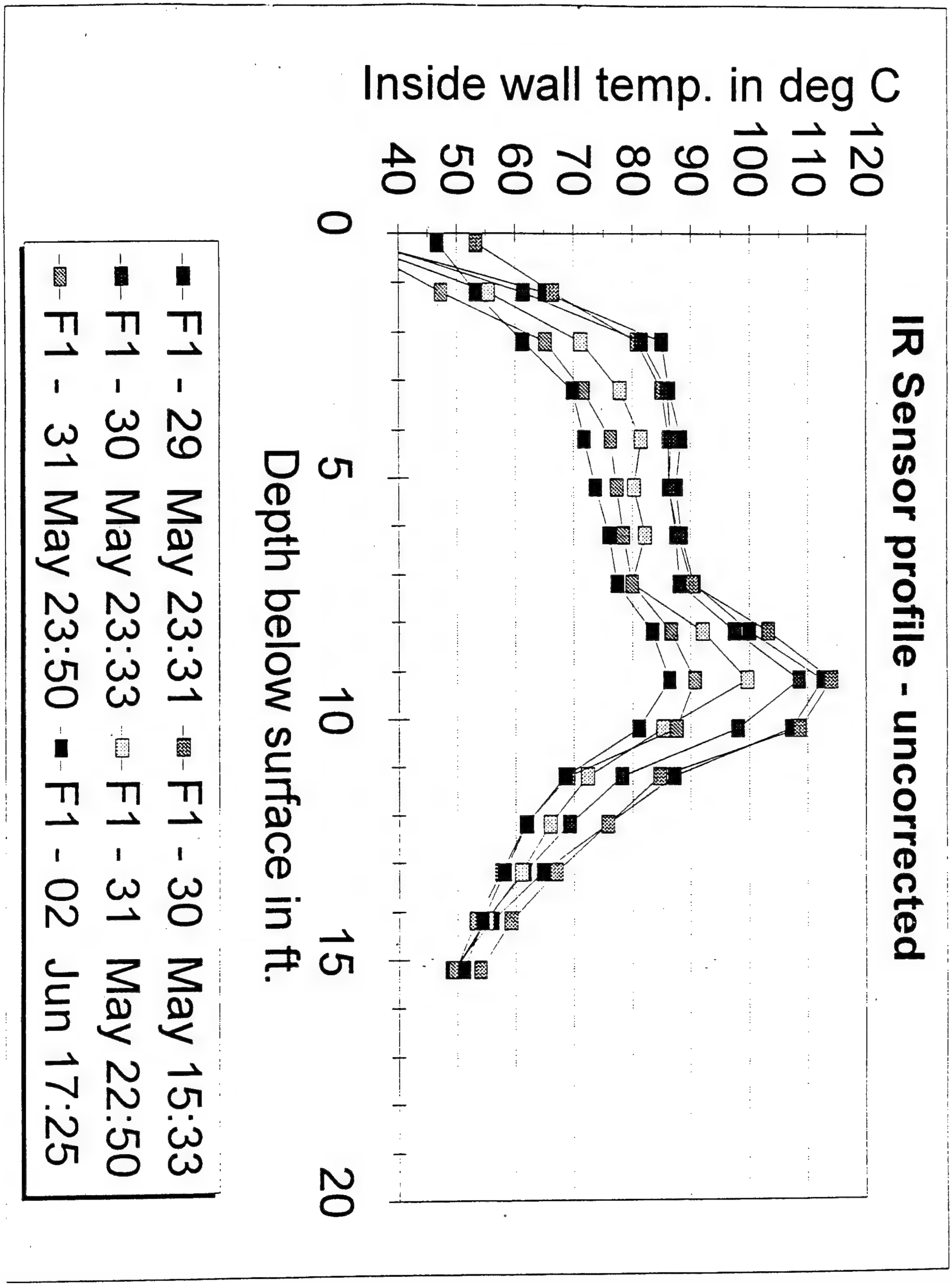
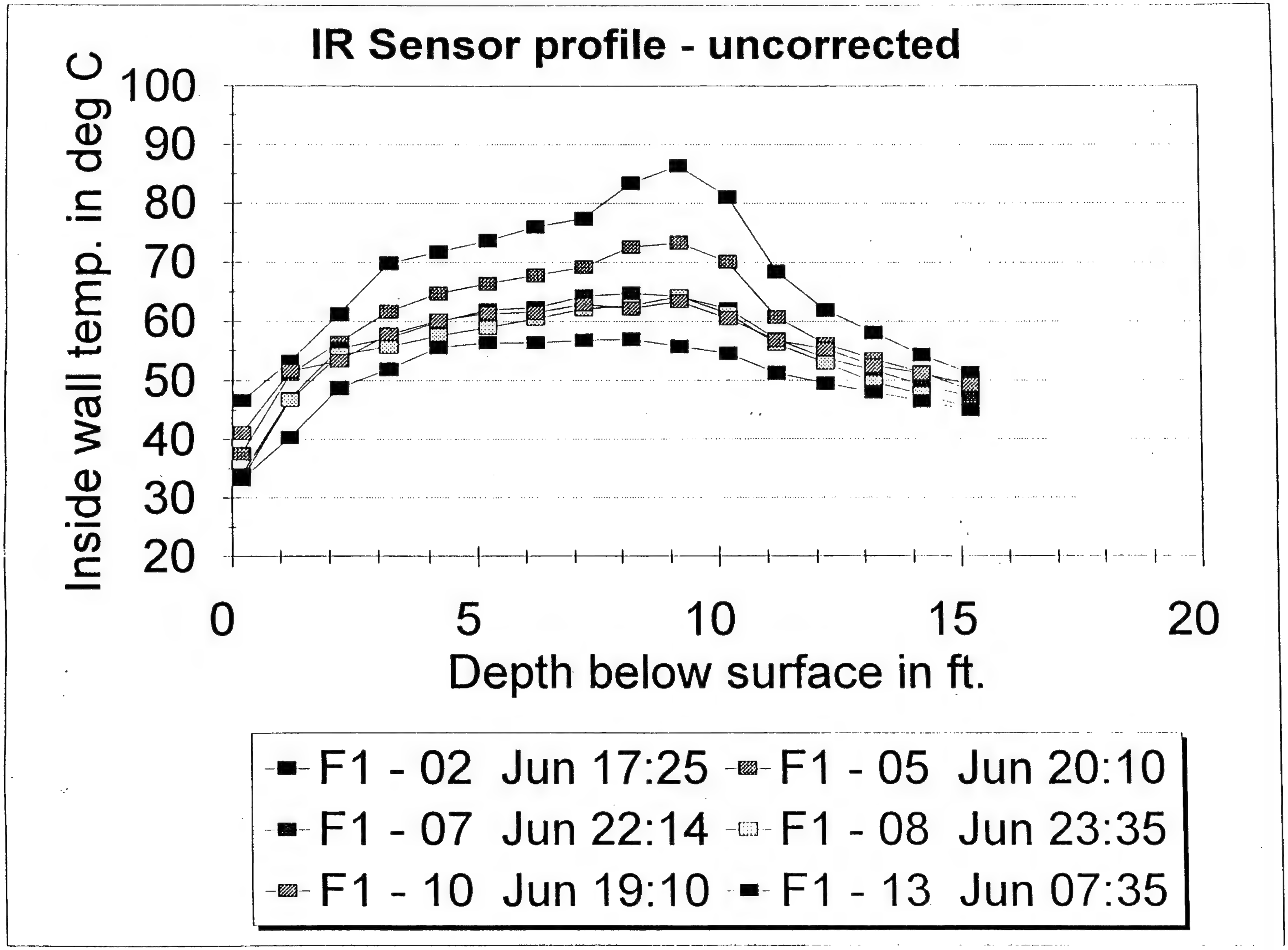


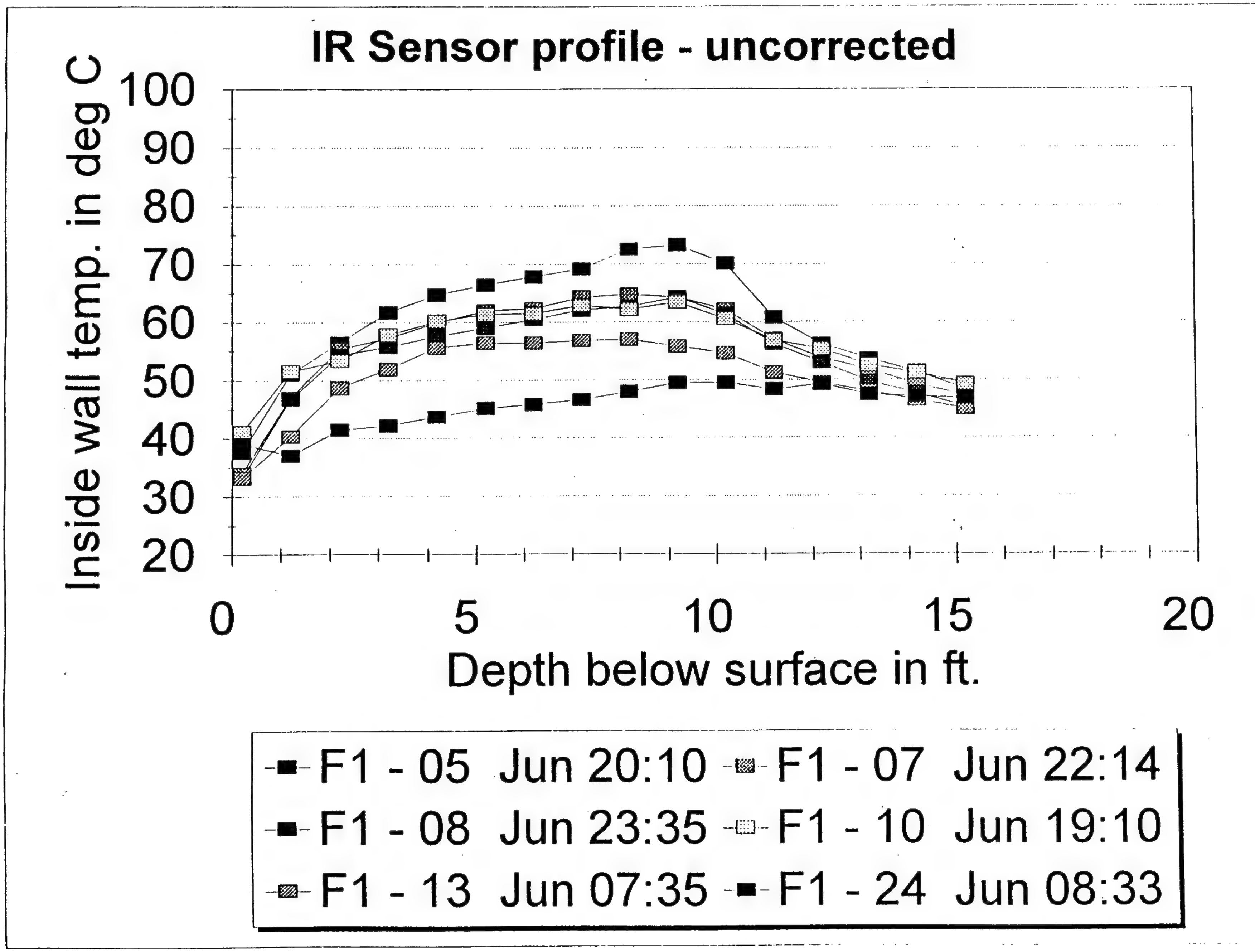
IR Sensor profile - uncorrected
Inside wall temp. in deg C
35
45
55
65
75
85
95
105
115
Depth below surface in ft.
0
5
10
15
20
F1 - 24 May 19:47
F1 - 25 May 18:44
F1 - 26 May 21:40
F1 - 27 May 21:15
F1 - 28 May 22:45
F1 - 29 May 23:31

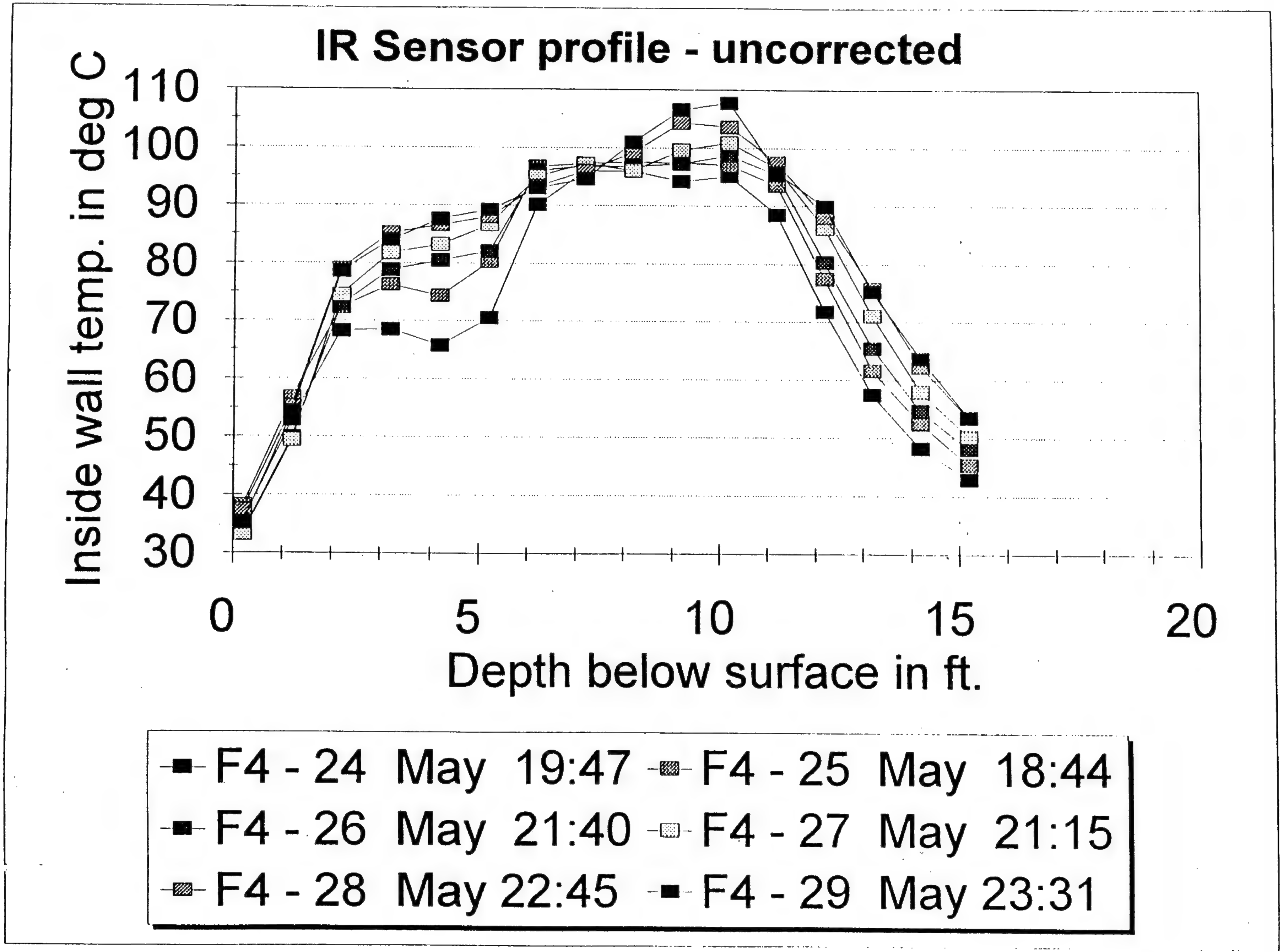


IR Sensor profile - uncorrected
Inside wall temp. in deg C
120
110
100
90
80
70
60
50
40
0
5
10
15
20
Depth below surface in ft.
F1 - 29 May 23:31
F1 - 30 May 15:33
F1 - 30 May 23:33
F1 - 31 May 22:50
F1 - 31 May 23:50
F1 - 02 Jun 17:25

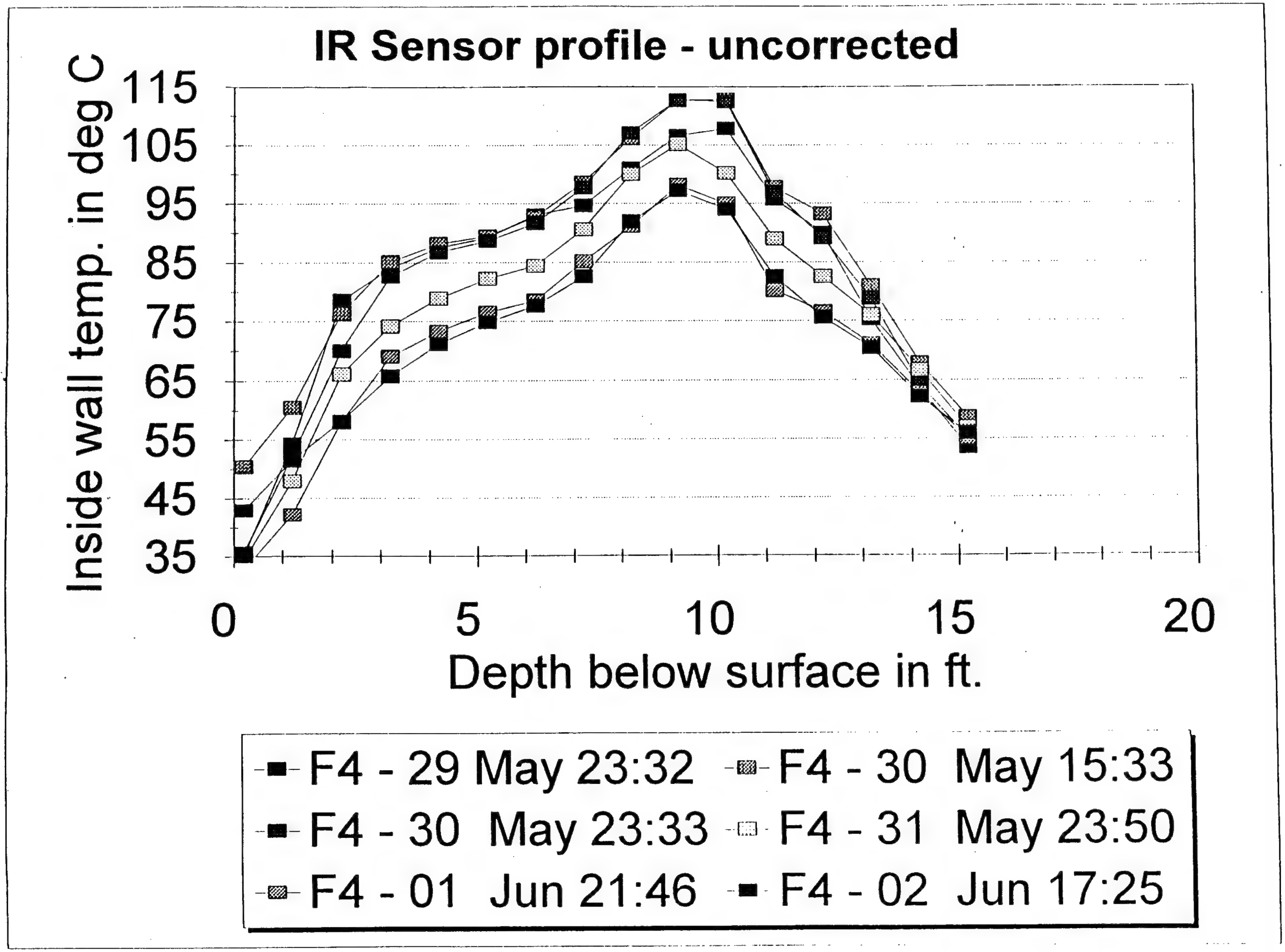


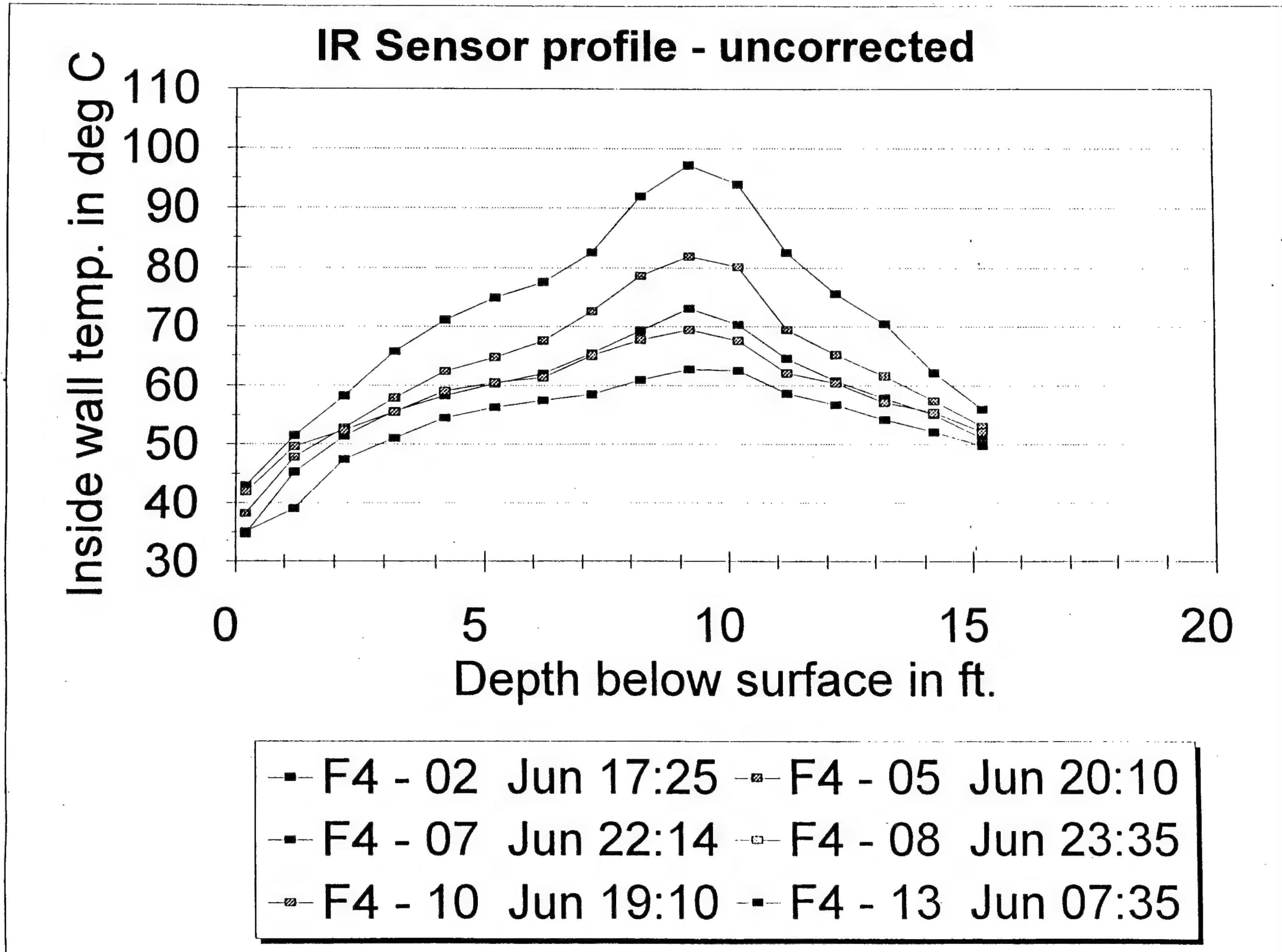
IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F1 - 02 Jun 17:25
F1 - 05 Jun 20:10
F1 - 07 Jun 22:14
F1 - 08 Jun 23:35
F1 - 10 Jun 19:10
F1 - 13 Jun 07:35

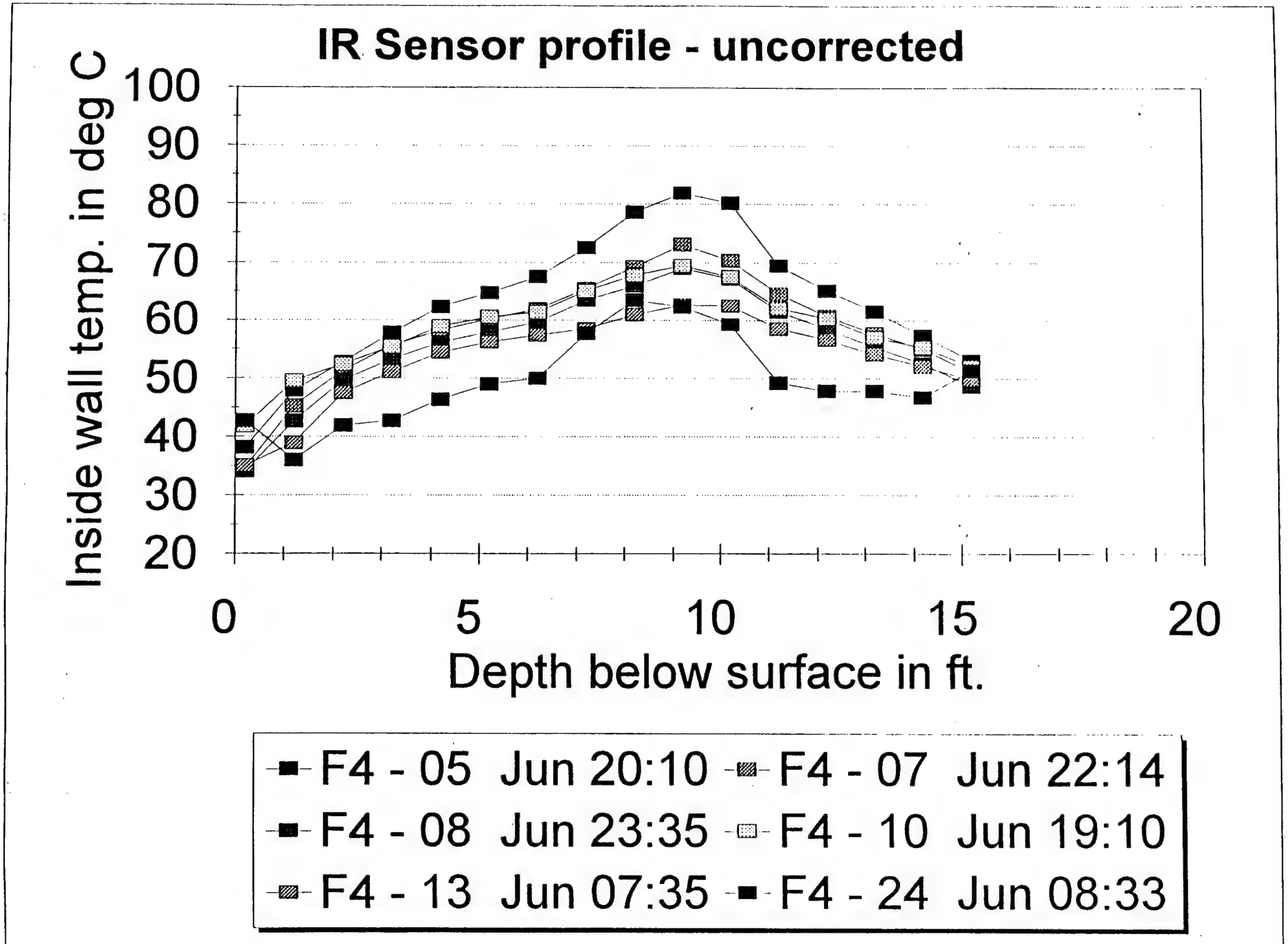

IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F1 - 05 Jun 20:10
F1 - 07 Jun 22:14
F1 - 08 Jun 23:35
F1 - 10 Jun 19:10
F1 - 13 Jun 07:35
F1 - 24 Jun 08:33

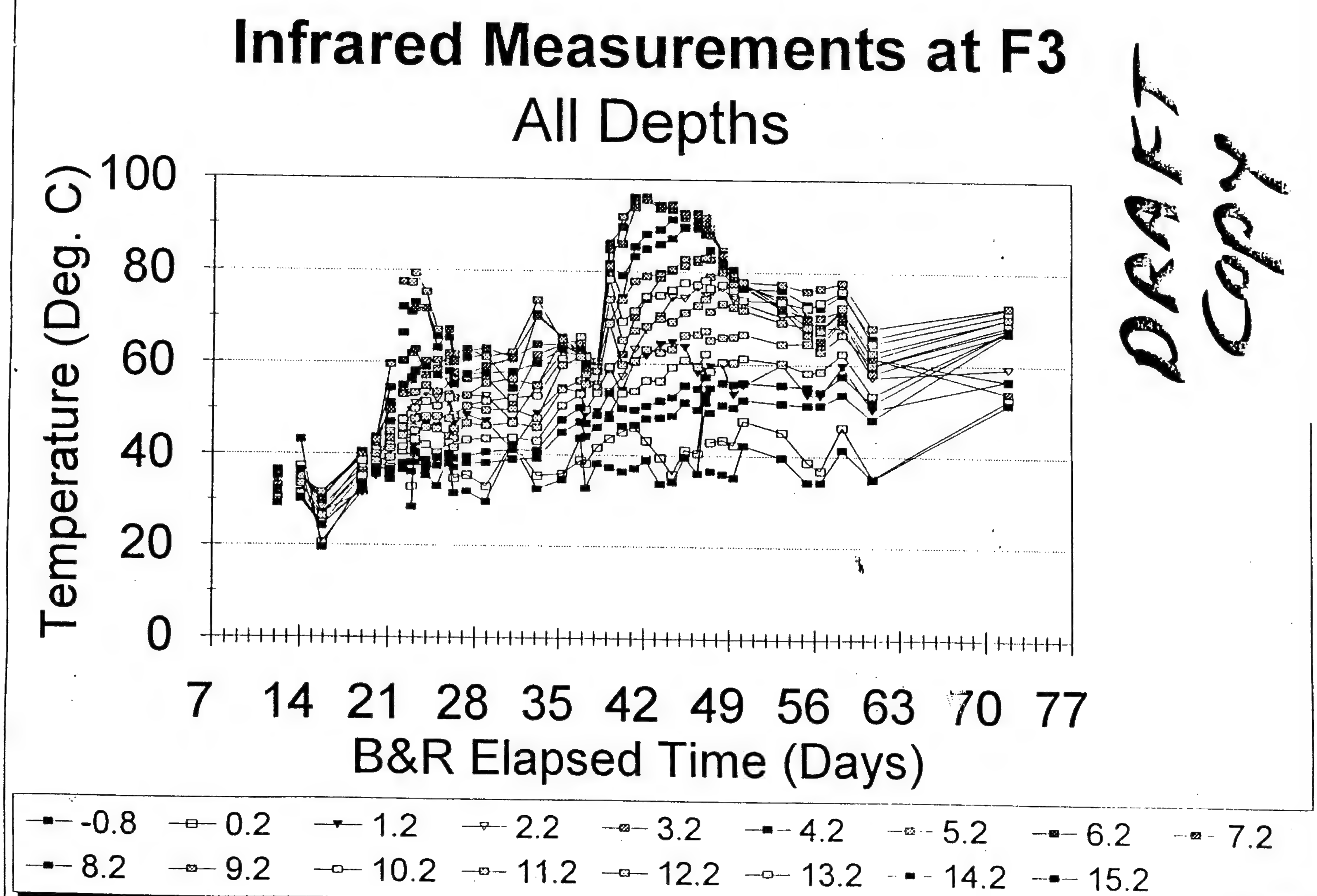


IR Sensor profile - uncorrected
Inside wall temp. in deg C
110
100
90
80
70
60
50
40
30
0
5
10
15
20
Depth below surface in ft.
F4 - 24 May 19:47
F4 - 25 May 18:44
F4 - 26 May 21:40
F4 - 27 May 21:15
F4 - 28 May 22:45
F4 - 29 May 23:31


IR Sensor profile - uncorrected
Inside wall temp. in deg C
115
105
95
85
75
65
55
45
35
0
5
10
15
20
Depth below surface in ft.
F4 - 29 May 23:32
F4 - 30 May 15:33
F4 - 30 May 23:33
F4 - 31 May 23:50
F4 - 01 Jun 21:46
F4 - 02 Jun 17:25


IR Sensor profile - uncorrected
Inside wall temp. in deg C
110
100
90
80
70
60
50
40
30
0
5
10
15
20
Depth below surface in ft.
F4 - 02 Jun 17:25
F4 - 05 Jun 20:10
F4 - 07 Jun 22:14
F4 - 08 Jun 23:35
F4 - 10 Jun 19:10
F4 - 13 Jun 07:35


IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F4 - 05 Jun 20:10
F4 - 07 Jun 22:14
F4 - 08 Jun 23:35
F4 - 10 Jun 19:10
F4 - 13 Jun 07:35
F4 - 24 Jun 08:33


Infrared Measurements at F3
All Depths
Temperature (Deg. C)
0
20
40
60
80
100
7
14
21
28
35
42
49
56
63
70
77
B&R Elapsed Time (Days)
-0.8
0.2
1.2
2.2
3.2
4.2
5.2
6.2
7.2
8.2
9.2
10.2
11.2
12.2
13.2
14.2
15.2

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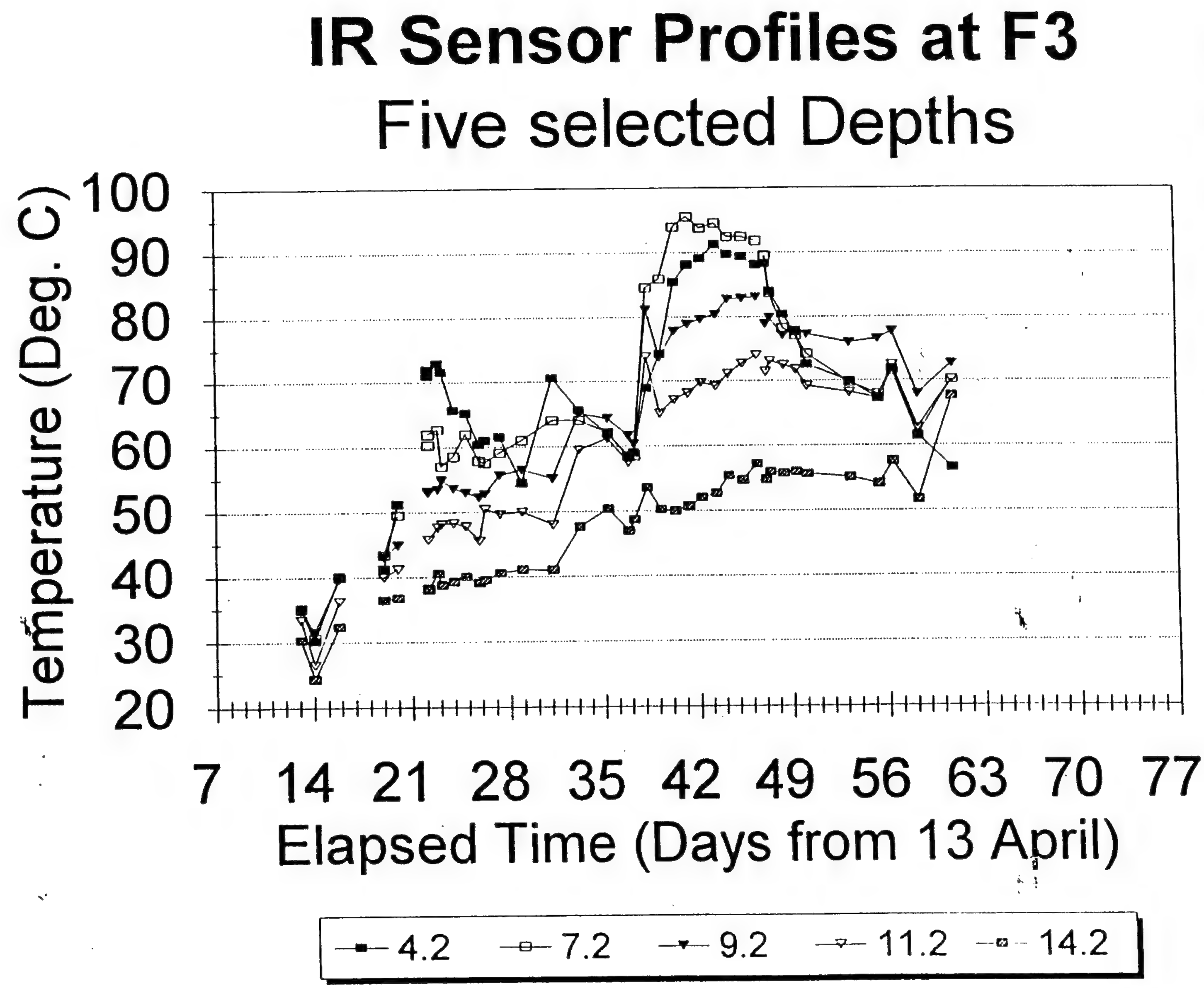
IR Sensor Profiles at F3
Five selected Depths
Temperature (Deg. C)
100
90
80
70
60
50
40
30
20
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
4.2
7.2
9.2
11.2
14.2

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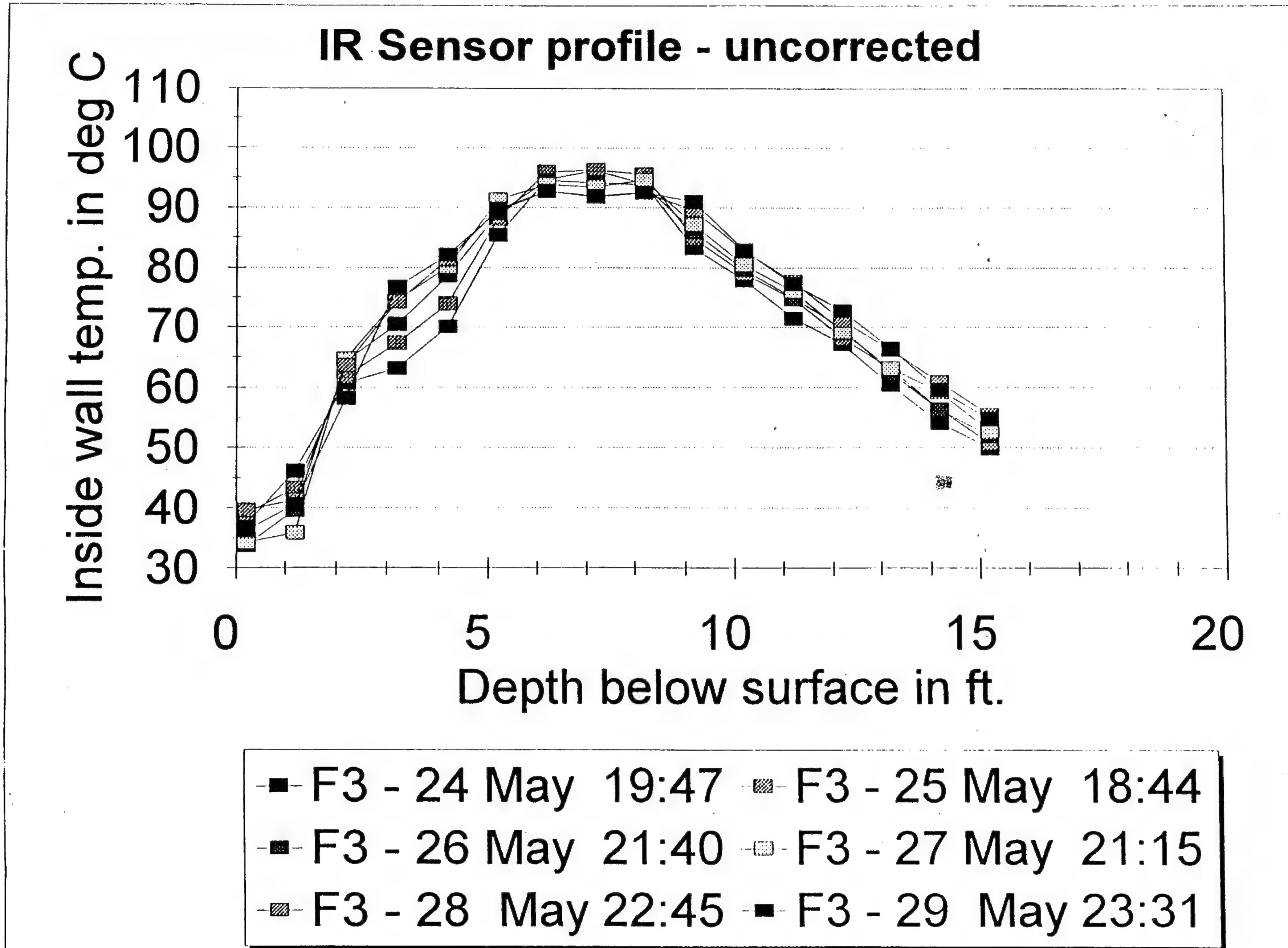
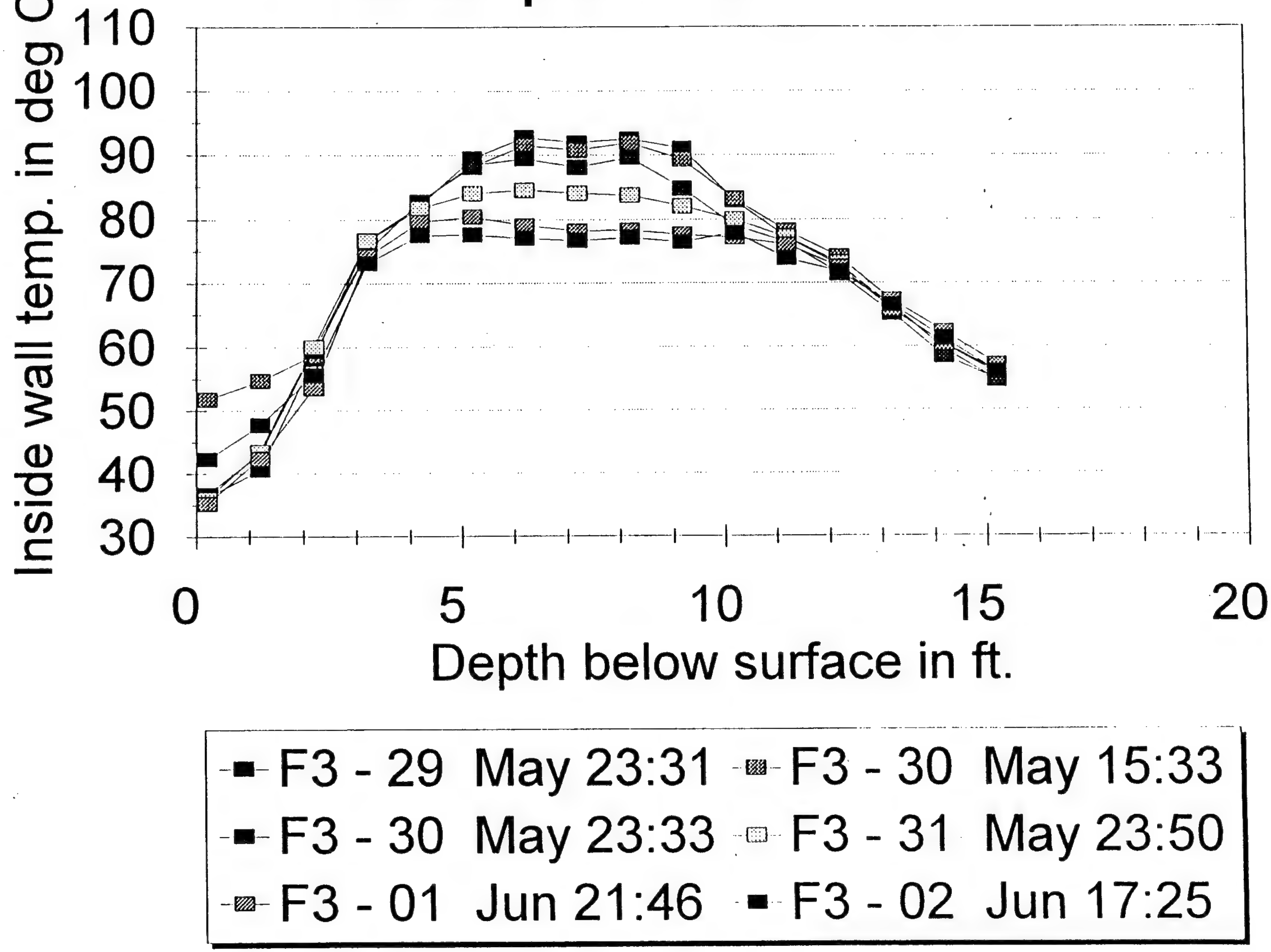
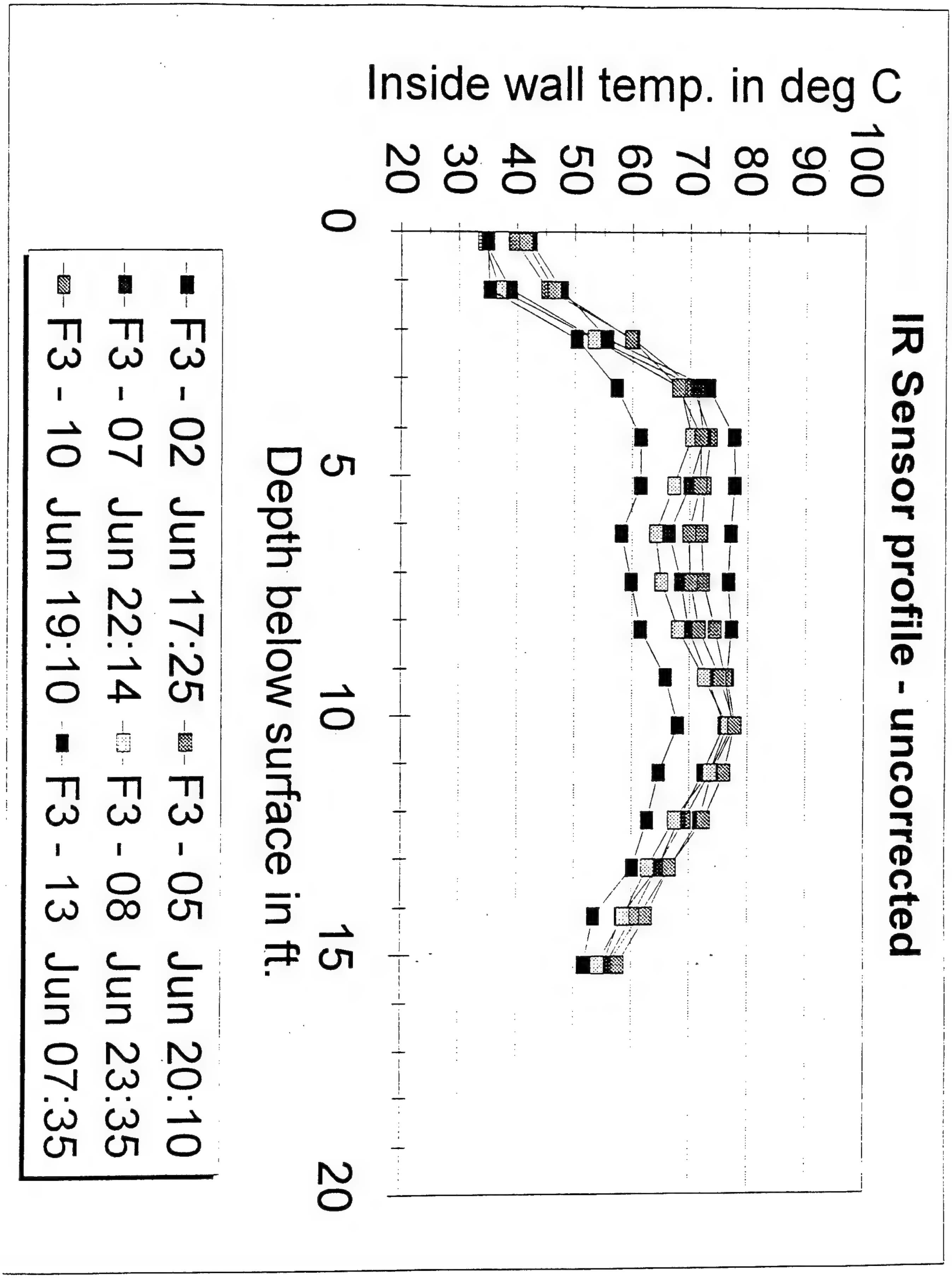
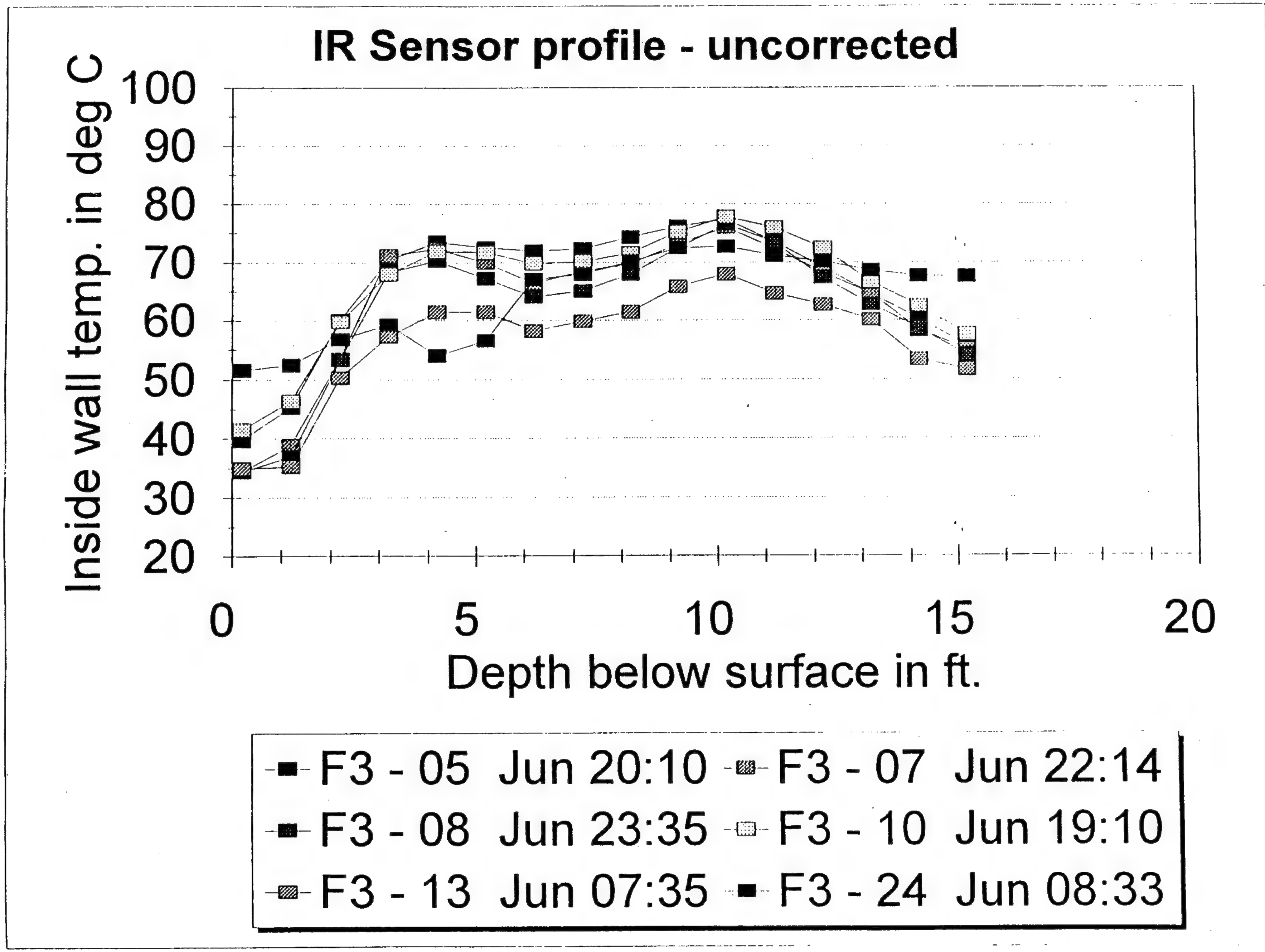

IR Sensor profile - uncorrected
Inside wall temp. in deg C
110
100
90
80
70
60
50
40
30
0
5
10
15
20
Depth below surface in ft.
F3 - 24 May 19:47
F3 - 25 May 18:44
F3 - 26 May 21:40
F3 - 27 May 21:15
F3 - 28 May 22:45
F3 - 29 May 23:31

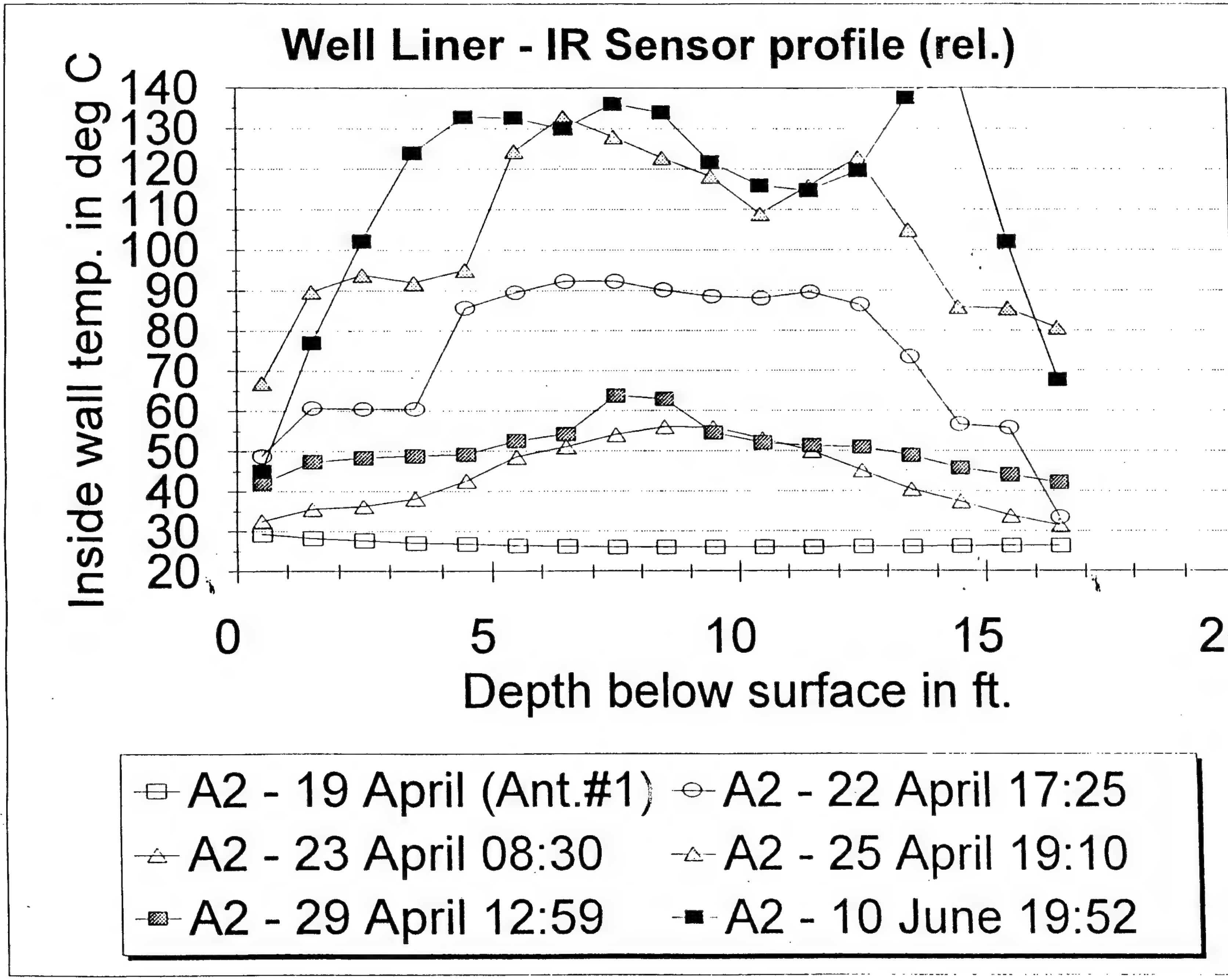
IR Sensor profile - uncorrected




IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F3 - 02 Jun 17:25
F3 - 05 Jun 20:10
F3 - 07 Jun 22:14
F3 - 08 Jun 23:35
F3 - 10 Jun 19:10
F3 - 13 Jun 07:35



IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F3 - 05 Jun 20:10
F3 - 07 Jun 22:14
F3 - 08 Jun 23:35
F3 - 10 Jun 19:10
F3 - 13 Jun 07:35
F3 - 24 Jun 08:33


Well Liner - IR Sensor profile (rel.)
Inside wall temp. in deg C
140
130
120
110
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
A2 - 19 April (Ant.#1)
A2 - 22 April 17:25
A2 - 23 April 08:30
A2 - 25 April 19:10
A2 - 29 April 12:59
A2 - 10 June 19:52

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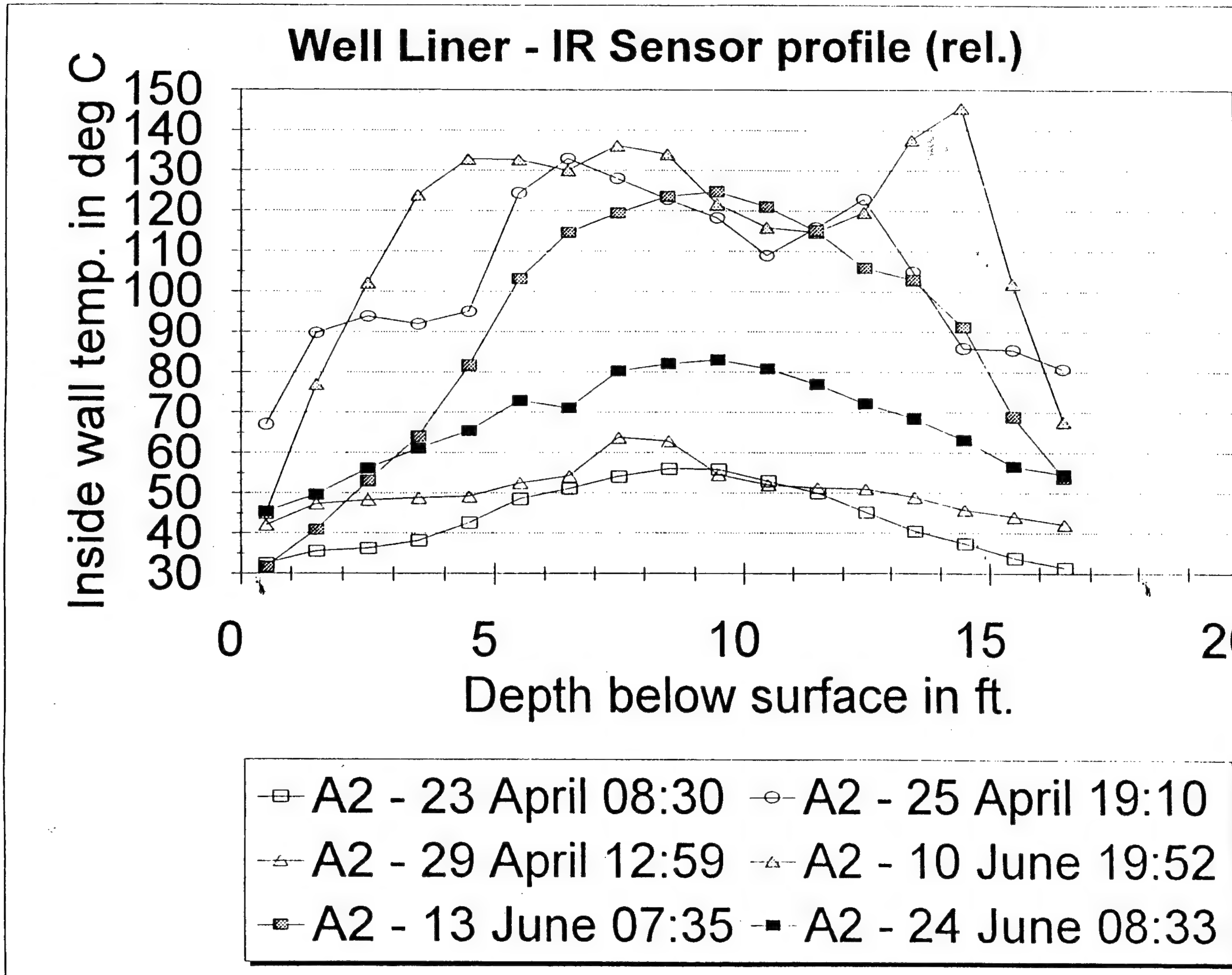
Well Liner - IR Sensor profile (rel.)
Inside wall temp. in deg C
150
140
130
120
110
100
90
80
70
60
50
40
30
0
5
10
15
20
Depth below surface in ft.
A2 - 23 April 08:30
A2 - 25 April 19:10
A2 - 29 April 12:59
A2 - 10 June 19:52
A2 - 13 June 07:35
A2 - 24 June 08:33

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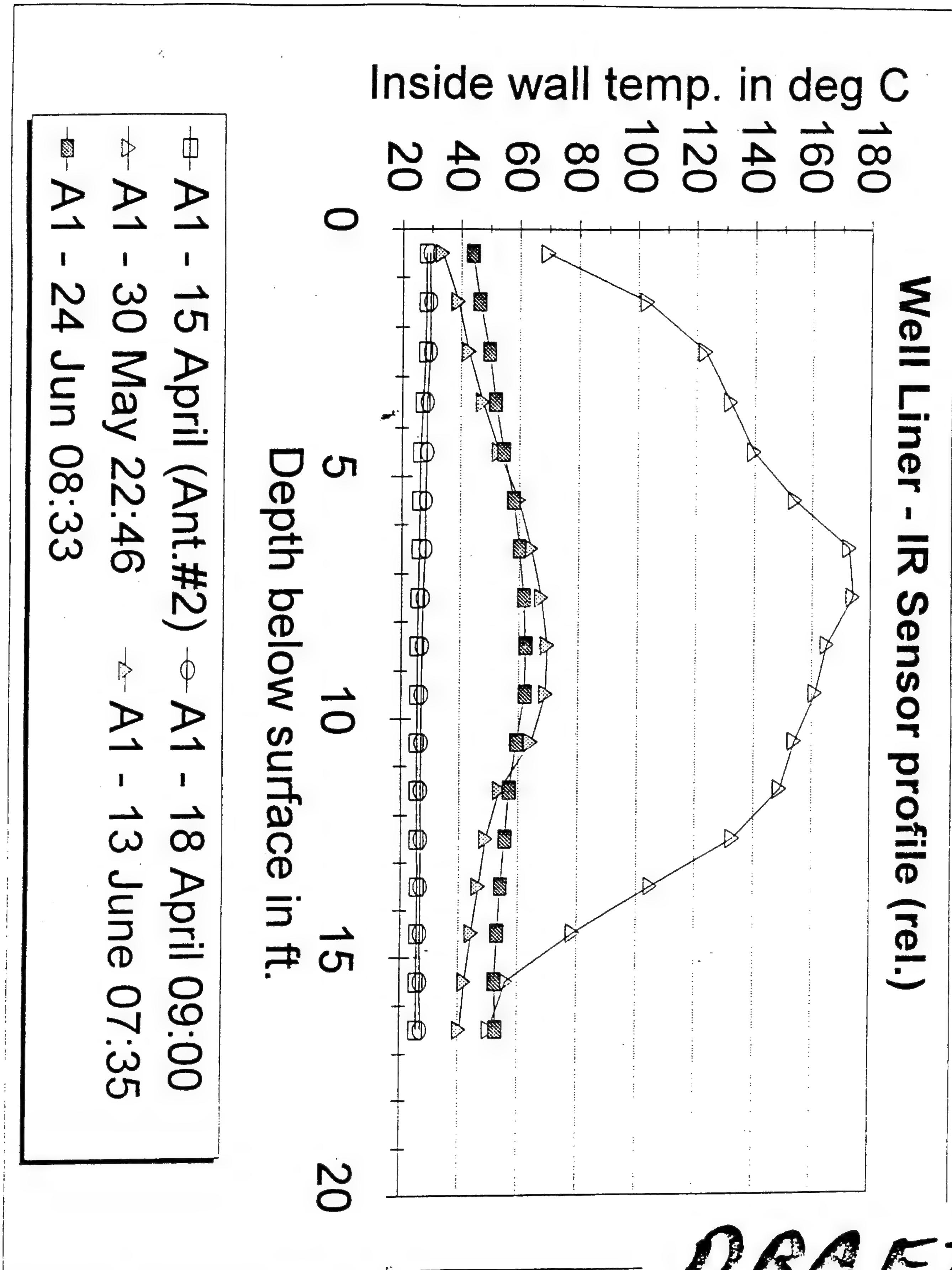

Well Liner - IR Sensor profile (rel.)
Inside wall temp. in deg C
180
160
140
120
100
80
60
40
20
0
5
10
15
20
Depth below surface in ft.
A1 - 15 April (Ant.#2)
A1 - 18 April 09:00
A1 - 30 May 22:46
A1 - 13 June 07:35
A1 - 24 Jun 08:33

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Summary of selected plots - Note that some may be in the main text with different scales

Note that in all of these charts the A1 refers to Applicator #1 and A2 to Applicator 2. In a post-test labeling correction Applicator #1 is now identified as being used to heat well A2 and Applicator #2 is used in A1.

- Tuning test plots of return loss for a test dipole antenna with a small diameter coaxial cable feed.
  - 74" test dipole at 4 depths - overlaid
  - 74" test dipole at 4 depths- 3D
  - 78" test dipole at 4 depths - overlaid
  - 78" test dipole at 4 depths - overlaid (displayed in main text, shifted freq. span)
  - 78" test dipole at 4 depths- 3D (displayed in main text, shifted freq. span)
  - 82" test dipole at 4 depths - overlaid
  - 82" test dipole at 4 depths- 3D
  - 86" test dipole at 4 depths - overlaid
  - 86" test dipole at 4 depths- 3D
  - 90" test dipole at 4 depths - overlaid
  - 90" test dipole at 4 depths- 3D

- Pre-heat, Return loss measurements on 20 April - The 27.12 MHz heating frequency is shown as a vertical dashed marker. The frequency span is the full measured sweep with using 401 measurement points. The -9.5 dB return loss is equal to a VSWR of 2.0.
  - Applicator #1 in well liner A2 (chart is labeled as A1, WKAF1001.01L)
  - Applicator #2 in well liner A1 (chart is labeled as A2, WKAF1002.01L)
  - Applicator #1 and #2 plots are overlay of WKAF1001.01L and WKAF1002.01L

- Pre-heat, Return loss measurement on 20 April using the tuner to optimally match the RF generator to the applicator. These plots are the tuner transformation of the match presented by WKAF1001.01L and WKAF1002.01L
  - Applicator #1 and #2 plots overlaid with tuner matching (WKAF2001.01L and WKAF2002.01L)

- Return loss measurements after heating starts Heating by applicator #1 in A2
  - Applicator #1 after approx 62 KWH
  - Applicator #1 after approx 1700 KWH
  - Applicator #1 first heating period - 20 April to 20 May measurement span (displayed in main text)
  - Applicator #2 heating period - 20 May to 7 June measurement span (displayed in main text)
  - Applicator #1 second heating period - 30 May to 10 June measurement span (displayed in main text)
  - Applicator #1 on 24 May, WKAF1113.01L
  - Applicator #2 on 24 May, WKAF1114.01L

- Insertion loss measurements - without minor correction of rigid coaxial path loss for this DRAFT
  - Preheat overlay of measurements made from Applicator #1 to Applicator #2. (displayed in main text)
    (measurements should be identical and are shown as this)
  - Applicator #1 - first heating period
  - Applicator #1 and #2 heated - comparison across entire program (displayed in main text)

END FILE: KELLYG.A

APPENDIX G - RF System Matching Measurements

Return loss and insertion loss.

RETURN LOSS

Definitions: Return loss = -20 $\log_{10} \rho$ where ρ is the reflection coefficient. This can be used to calculate the VSWR.

$$\boxed{VSWR = \textit{voltage standing wave ratio} = \frac{1+\rho}{1-\rho}}$$

The plots have been displayed in terms of return loss to better display changes in absorption of RF energy by the soil surrounding the applicator. The numbers for return loss are displayed in negative decibels (dB). The negative sign is due to the reference point of the measurement and the decibels are a logarithmic notation of reflected point. Where 3 dB indicates a 50% change in power, 10 dB a factor of 10 and 20 dB a factor of 100.

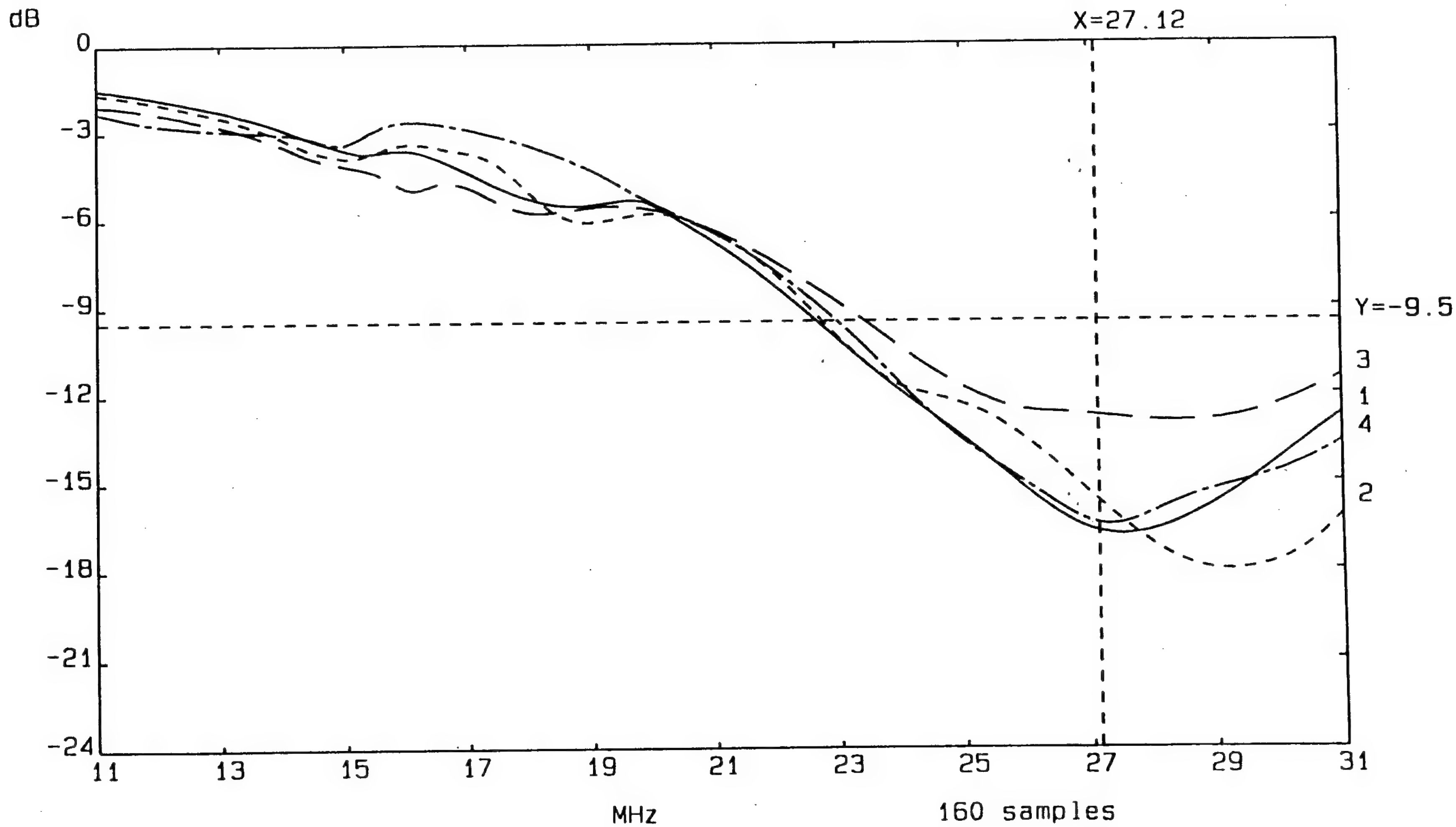
Large values of return loss indicate high levels of absorption (e.g. 32 dB) and small negative values (6.02 dB) indicate low levels of absorption which means that energy is reflected back to the tuner and the RF generator. Large amounts of energy being reflected is indicated by a high VSWR number. The goal is to have a low VSWR. The following table can be used to interpret the plots.

	VSWR	Return Loss (dB)	
	1.0	∞	
	1.05	32.25	This is an ideal practical value, it is typically the value the tuner presents to RF generator after it has been adjusted to match the load.
	1.20	20.82	
	1.5	13.98	
>>	2	9.5	This is the marker line on the plots of applicator matching. This level of return loss indicates that 10% of the power is being reflected back from applicator and approximately 90% is being delivered to the soil.
	3.0	6.02	
	5.0	3.52	Nearly 50% of the power is being reflected
	10.0	1.74	
	∞	0.00	All power is reflected back

INSERTION LOSS

This is a measurement of the power lost on the transmission path between Applicator #1 and Applicator #2. The measurement is made in decibels (dB). A 3 dB change in insertion loss indicates that the power received at on applicator has changed by 50%.

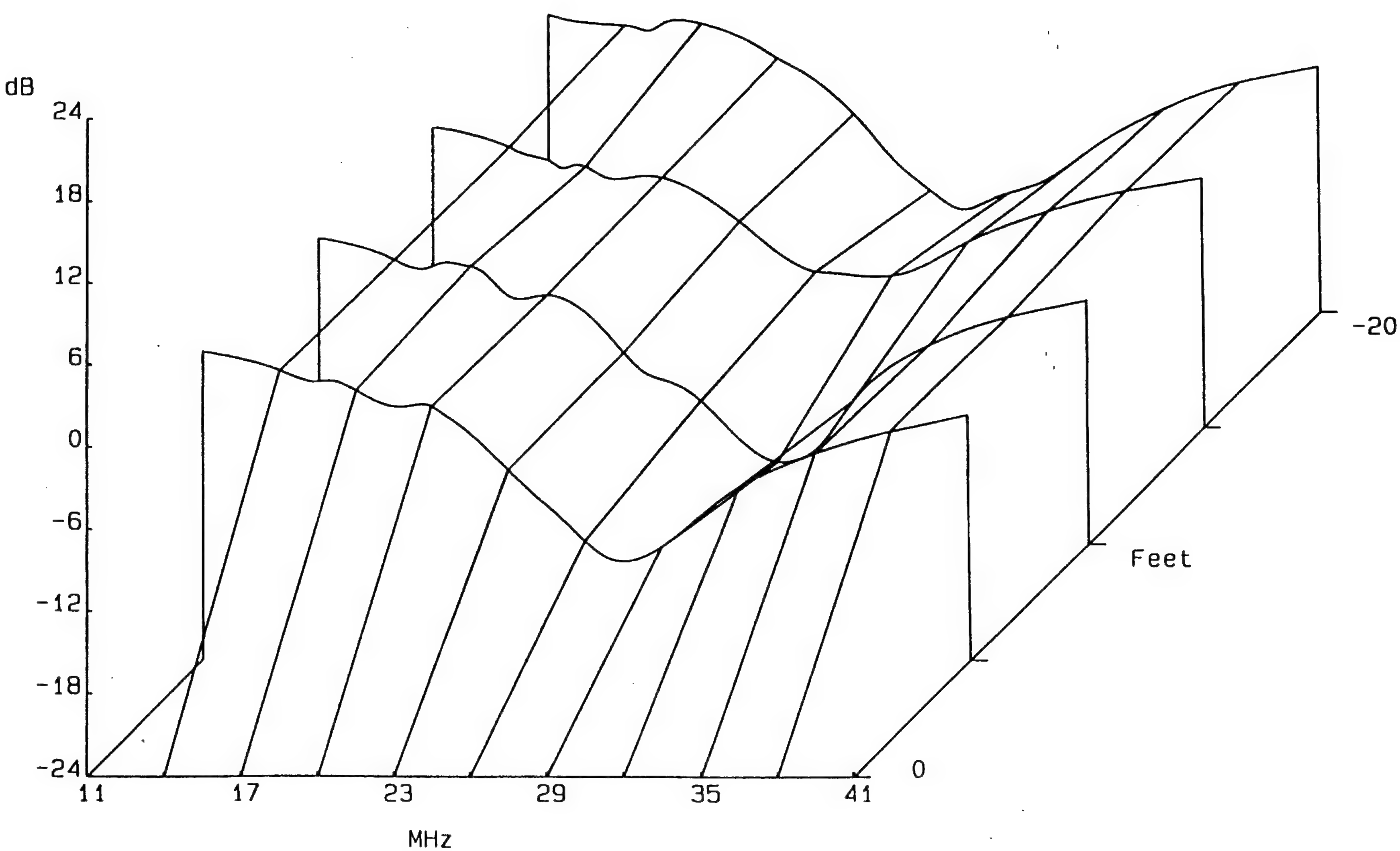
Scan of A2



1 WKAF0117.01L #1 Setup 74" w/cable at -5', Return Loss 1-Apr-94 17:49:40
2 WKAF0118.01L #1 Setup 74" w/cable at -10', Return Loss 1-Apr-94 17:50:18
3 WKAF0119.01L #1 Setup 74" w/cable at -15', Return Loss 1-Apr-94 17:51:43
4 WKAF0120.01L #1 Setup 74" w/cable at -20', Return Loss 1-Apr-94 17:53:13

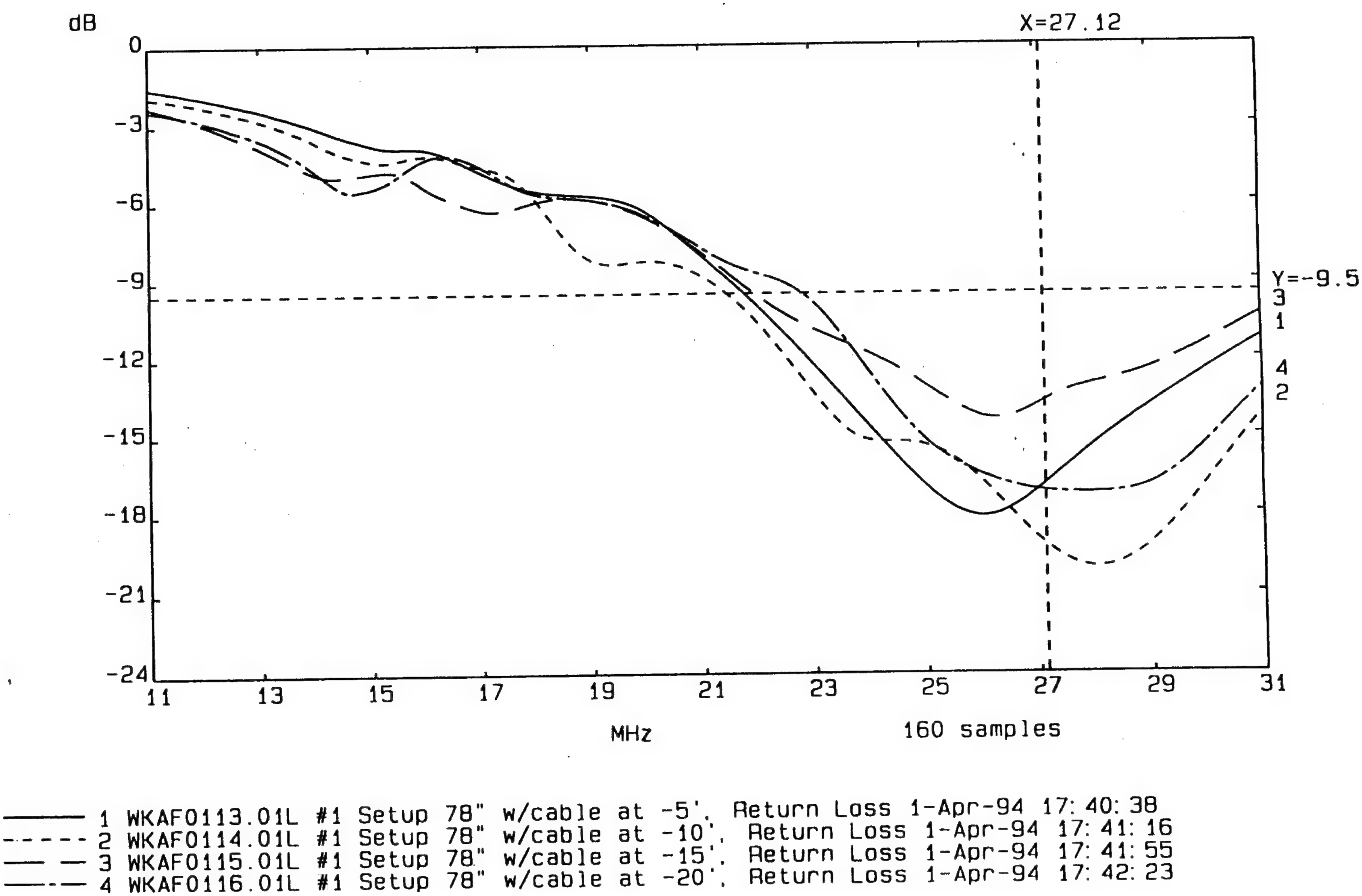
16 Dec-94

SCAN of A2 -WKAF0117.01L #1 Setup 74", Return Loss 1-Apr-94 17: 49: 40



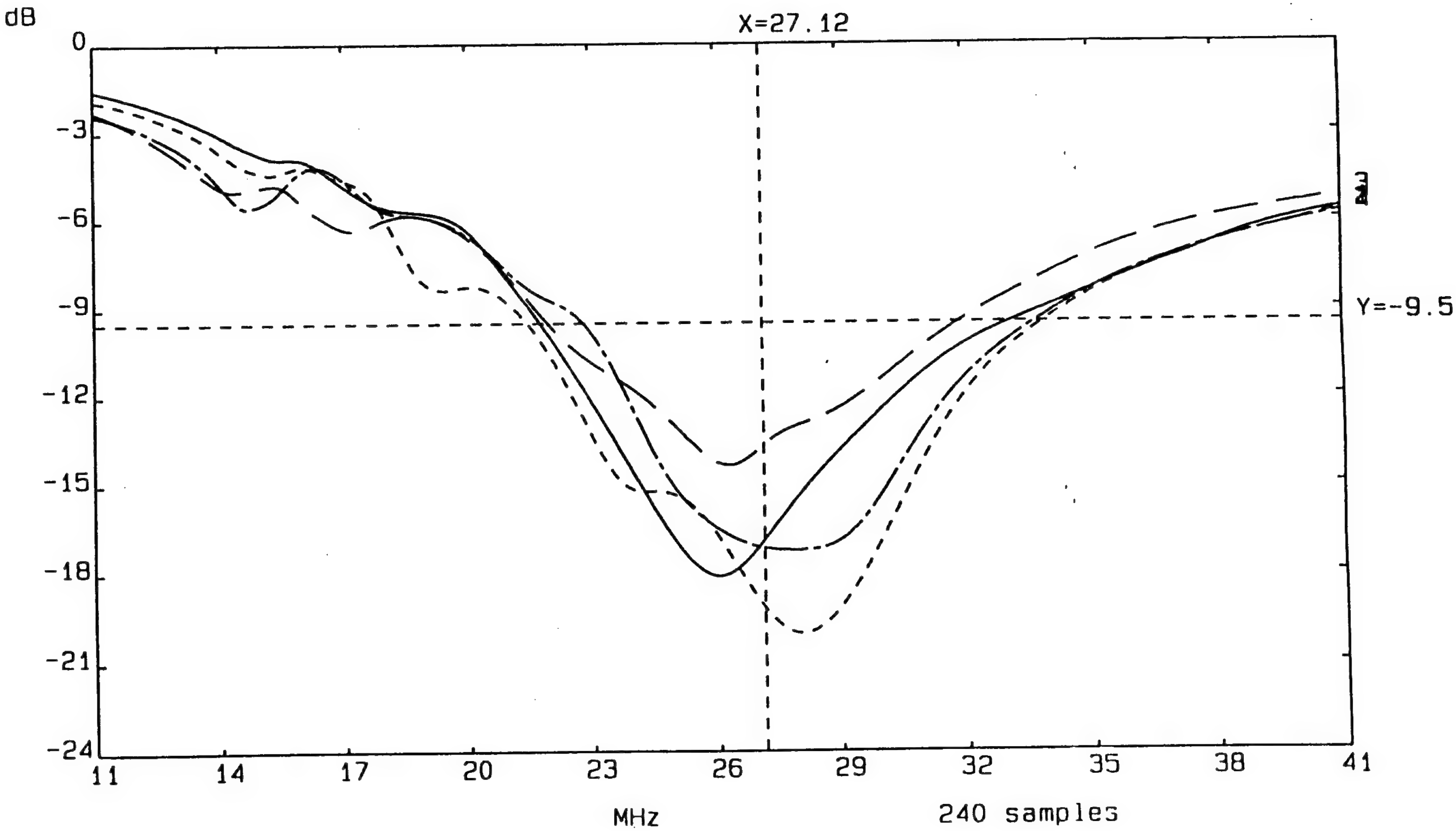
17-Dec-94

Scan of A2



16-Dec-94

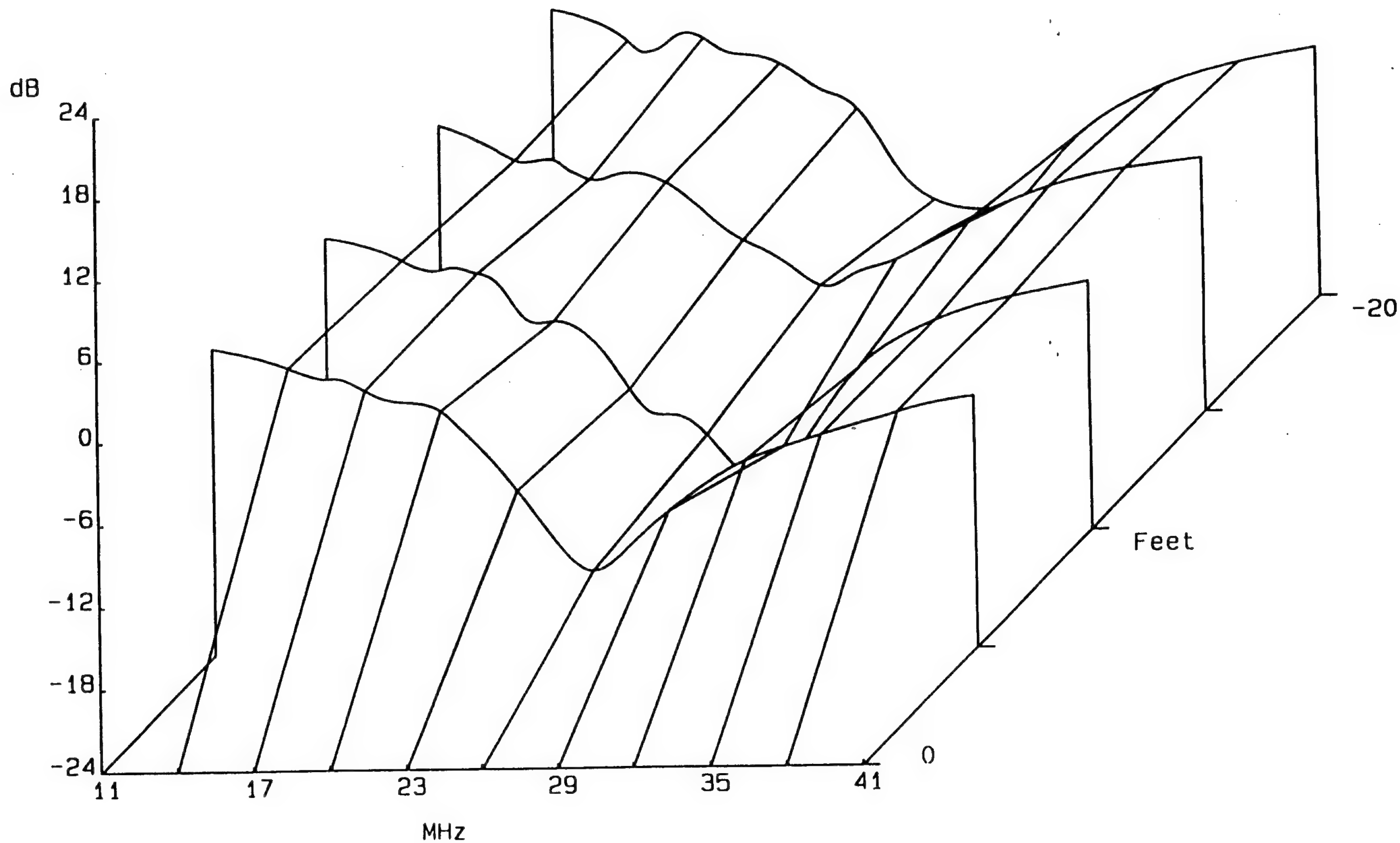
Scan of A2



1 WKAF0113.01L #1 Setup 78" w/cable at -5', Return Loss 1-Apr-94 17:40:38
2 WKAF0114.01L #1 Setup 78" w/cable at -10', Return Loss 1-Apr-94 17:41:16
3 WKAF0115.01L #1 Setup 78" w/cable at -15', Return Loss 1-Apr-94 17:41:55
4 WKAF0116.01L #1 Setup 78" w/cable at -20', Return Loss 1-Apr-94 17:42:23

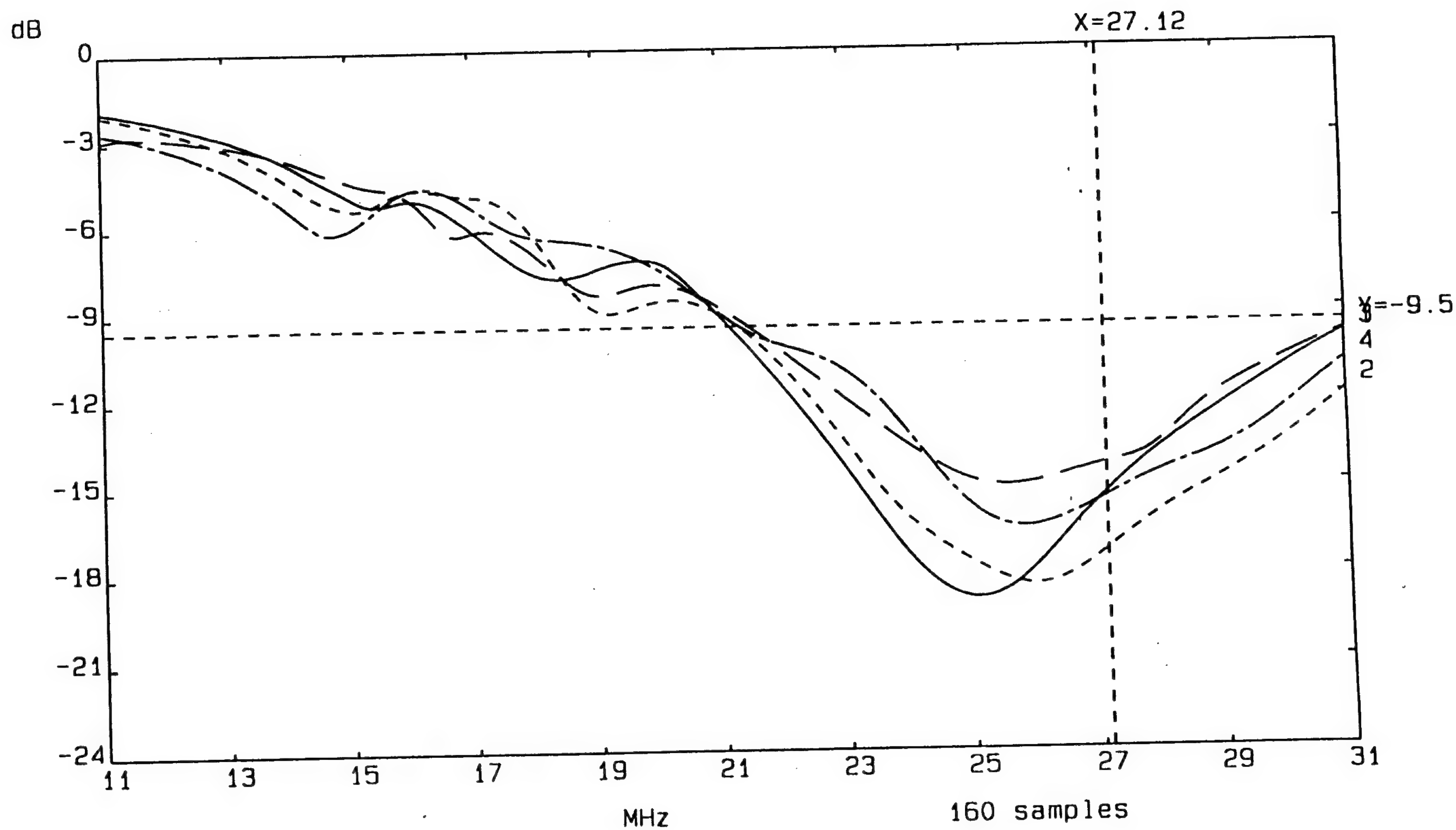
16-Dec-94

Scan of A2 -WKAF0113.01L #1 Setup 78", Return Loss 1-Apr-94 17: 40: 38



16-Dec-94

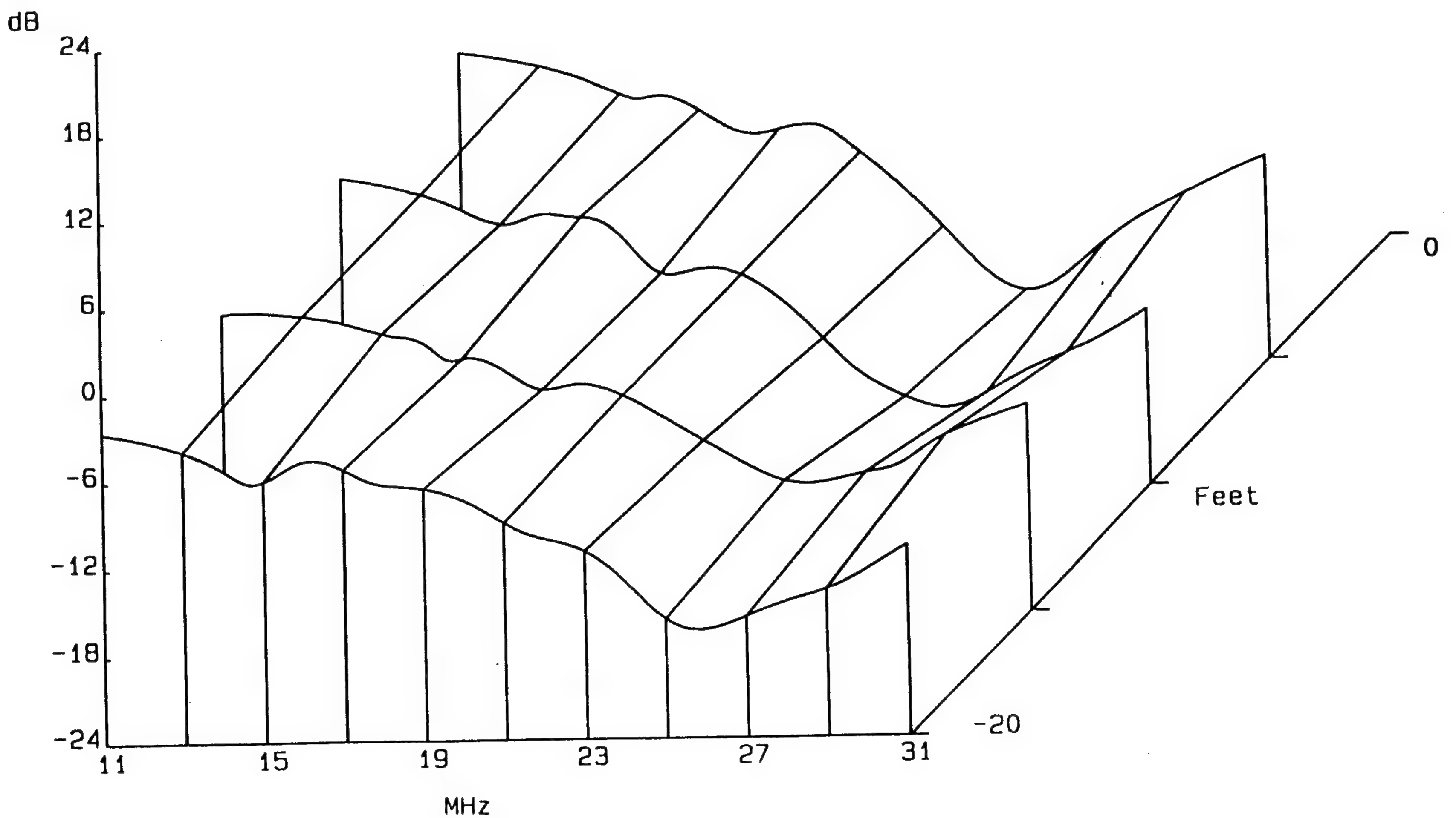
Scan of A2



1 WKAF0109.01L #1 Setup 82" w/cable at -5', Return Loss 1-Apr-94 17:21:36
2 WKAF0110.01L #1 Setup 82" w/cable at -10', Return Loss 1-Apr-94 17:22:10
3 WKAF0111.01L #1 Setup 82" w/cable at -15', Return Loss 1-Apr-94 17:22:38
4 WKAF0112.01L #1 Setup 82" w/cable at -20', Return Loss 1-Apr-94 17:23:13

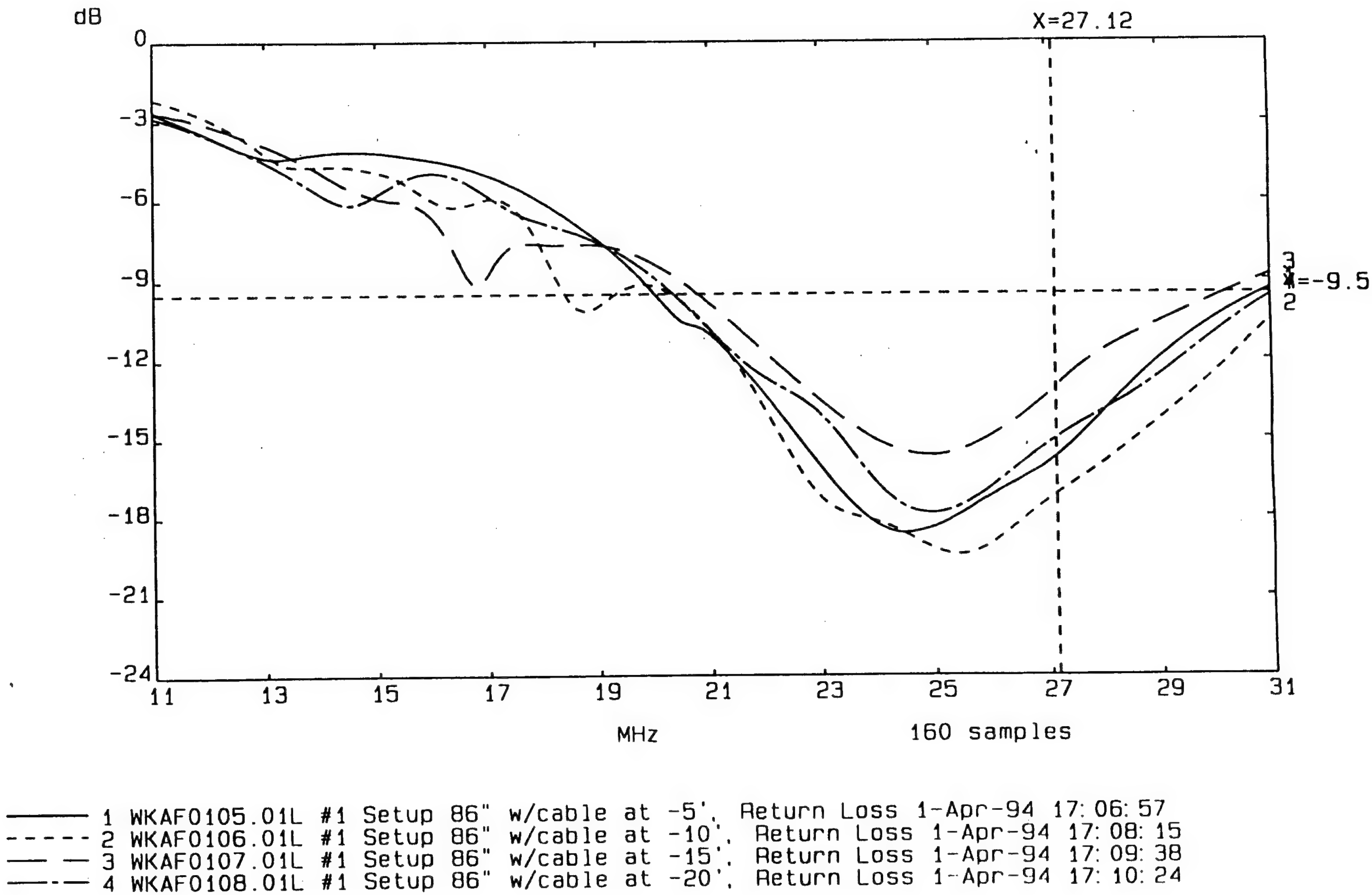
16-Dec-94

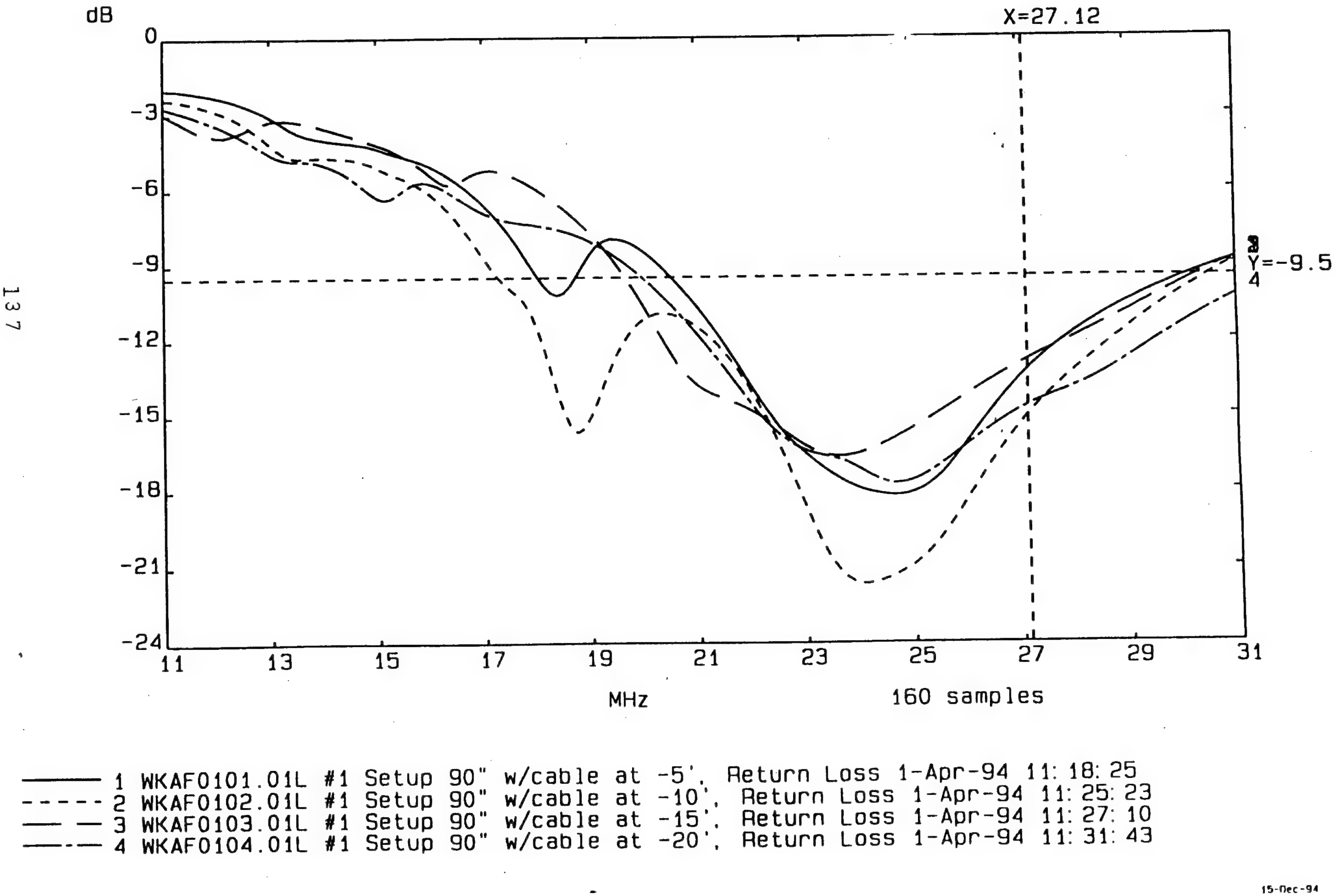
Scan of A2 - WKAF0109.01L #1 Setup 82", Return Loss 1-Apr-94 17:21:36



15-Dec-94

Scan of A2

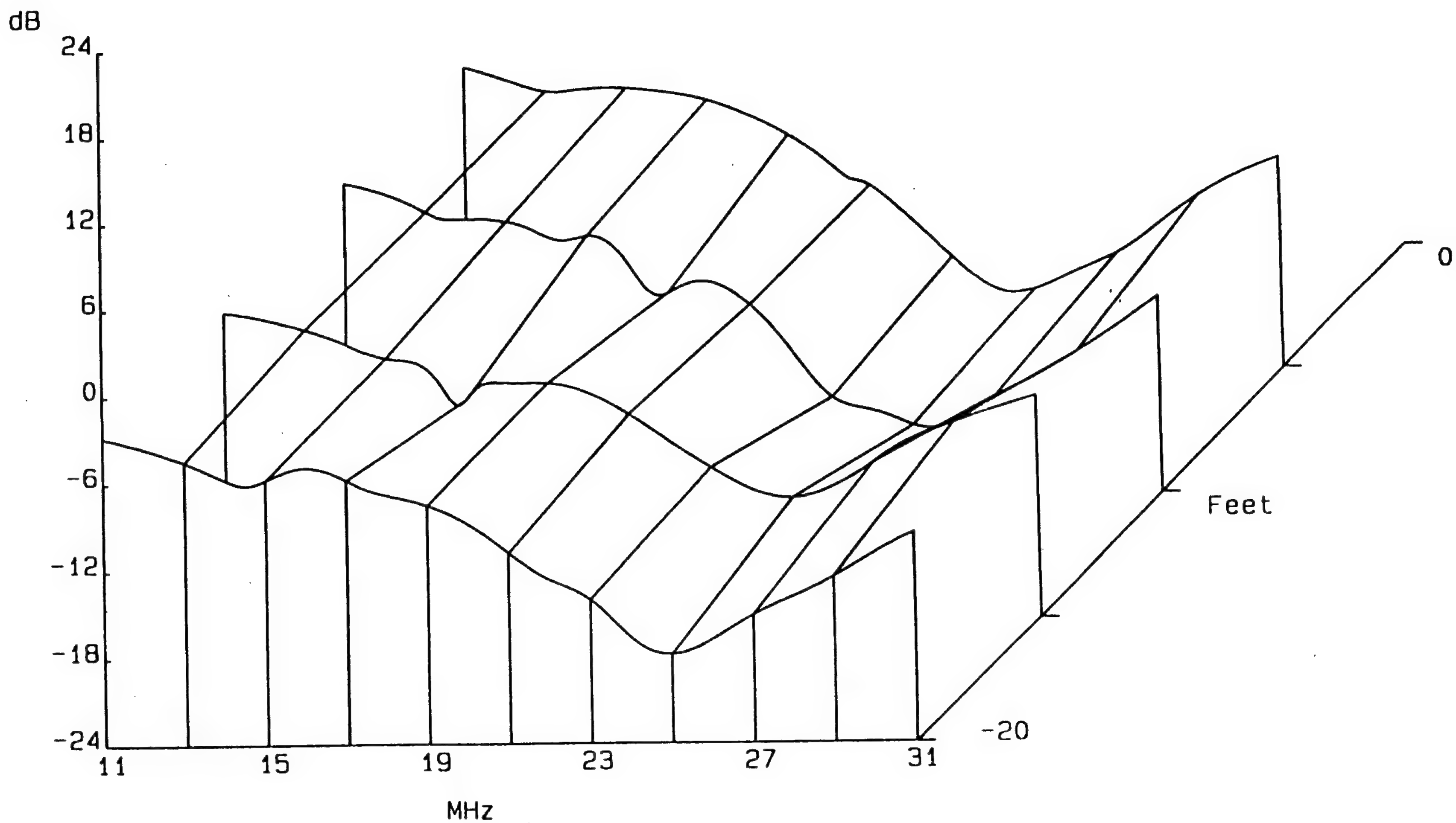

dB
0
-3
-6
-9
-12
-15
-18
-21
-24
11
13
15
17
19
21
23
25
27
29
31
MHz
160 samples
X=27.12
Y=-9.5
3
2
1 WKAF0105.01L #1 Setup 86" w/cable at -5', Return Loss 1-Apr-94 17:06:57
2 WKAF0106.01L #1 Setup 86" w/cable at -10', Return Loss 1-Apr-94 17:08:15
3 WKAF0107.01L #1 Setup 86" w/cable at -15', Return Loss 1-Apr-94 17:09:38
4 WKAF0108.01L #1 Setup 86" w/cable at -20', Return Loss 1-Apr-94 17:10:24



137

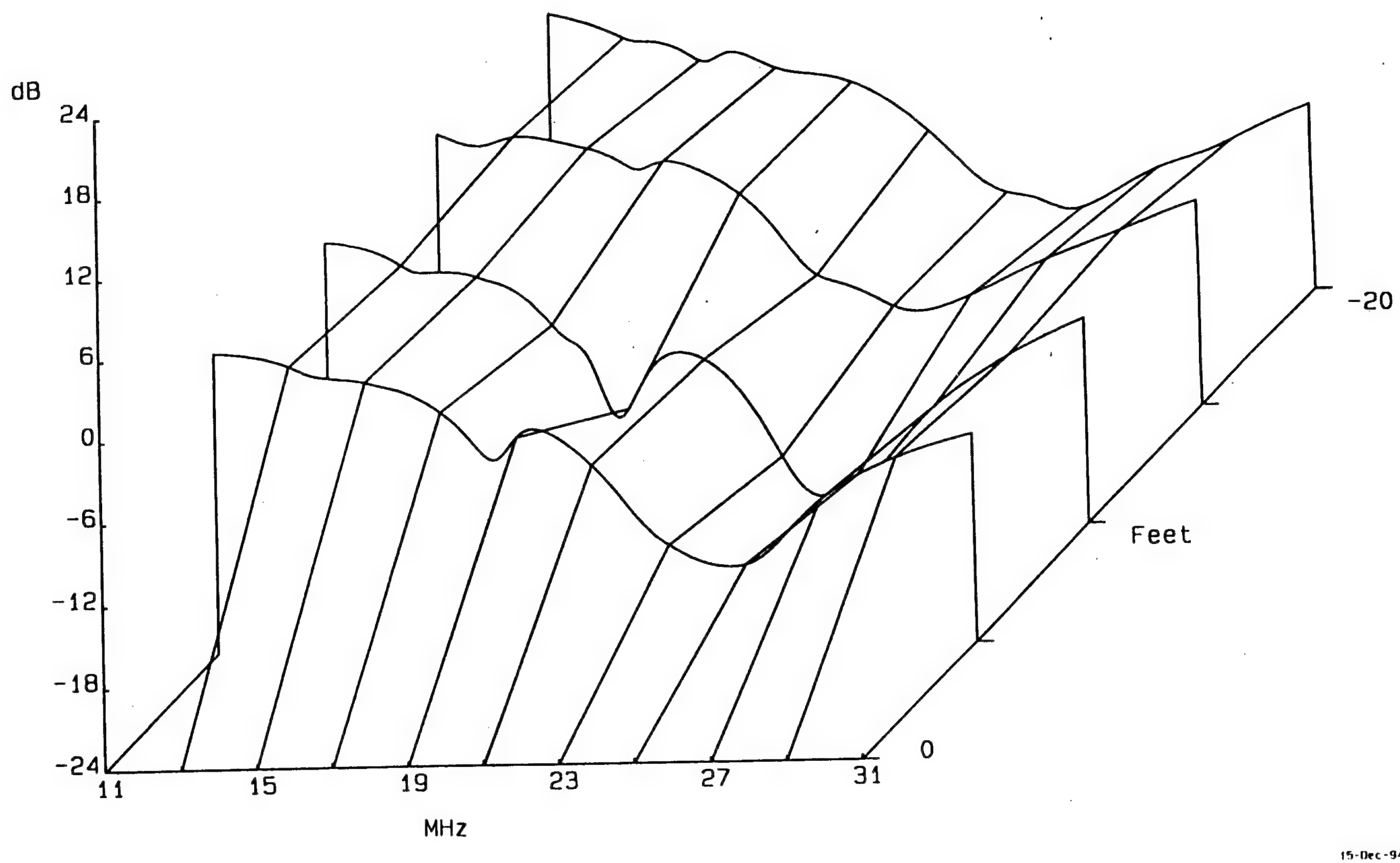
W1000.PLT

Scan of A2 - WKAF0105.01L #1 Setup 86", Return Loss 1-Apr-94 17:06:57

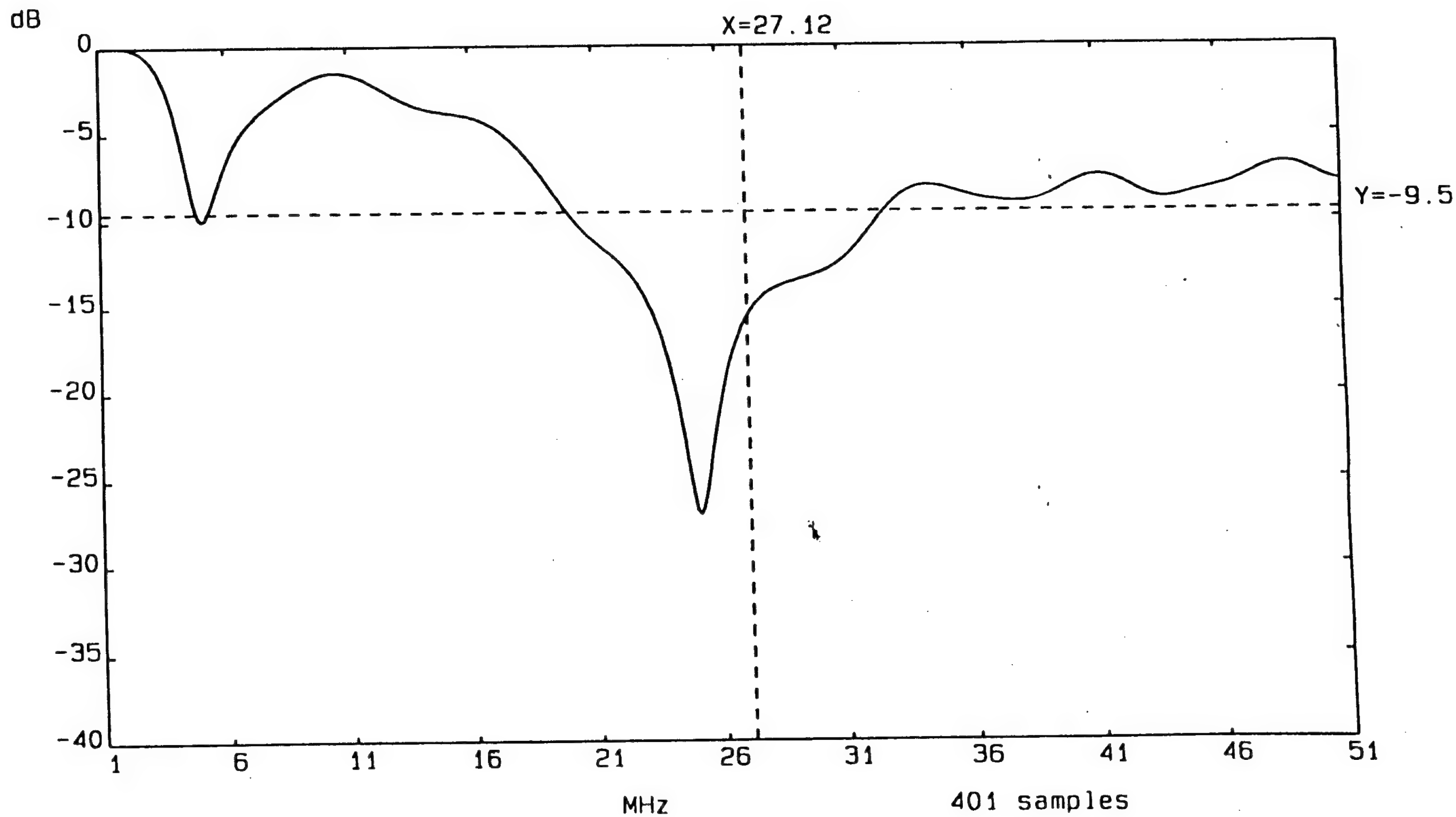


15-Dec-94

WKAF0101.01L #1 Setup 90" w/cable at -5'. Return Loss 1-Apr-94 11:18:25



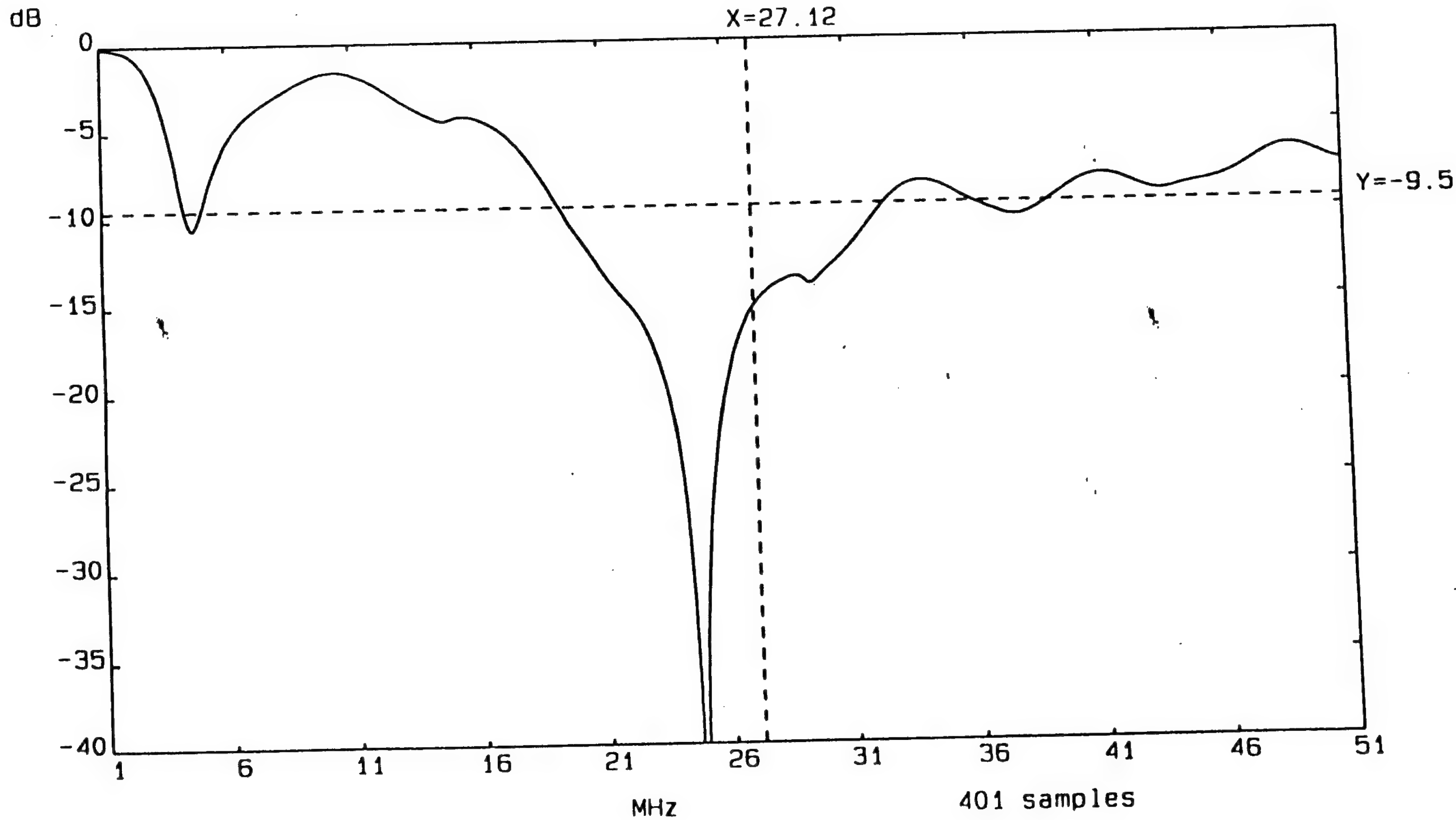
WKAF1001.01L Heat 1 feed A1-pre heat, Return Loss 20-Apr-94 16:48:35



Instr=HP3577A, H units=Hz, V units=dB, Npw= 401, VSCL= 10 T1,
Freq MHz= 26, H span MHz= 50, Res KHz= 1, Avg= 1, Wscale= 100.

21-May-94

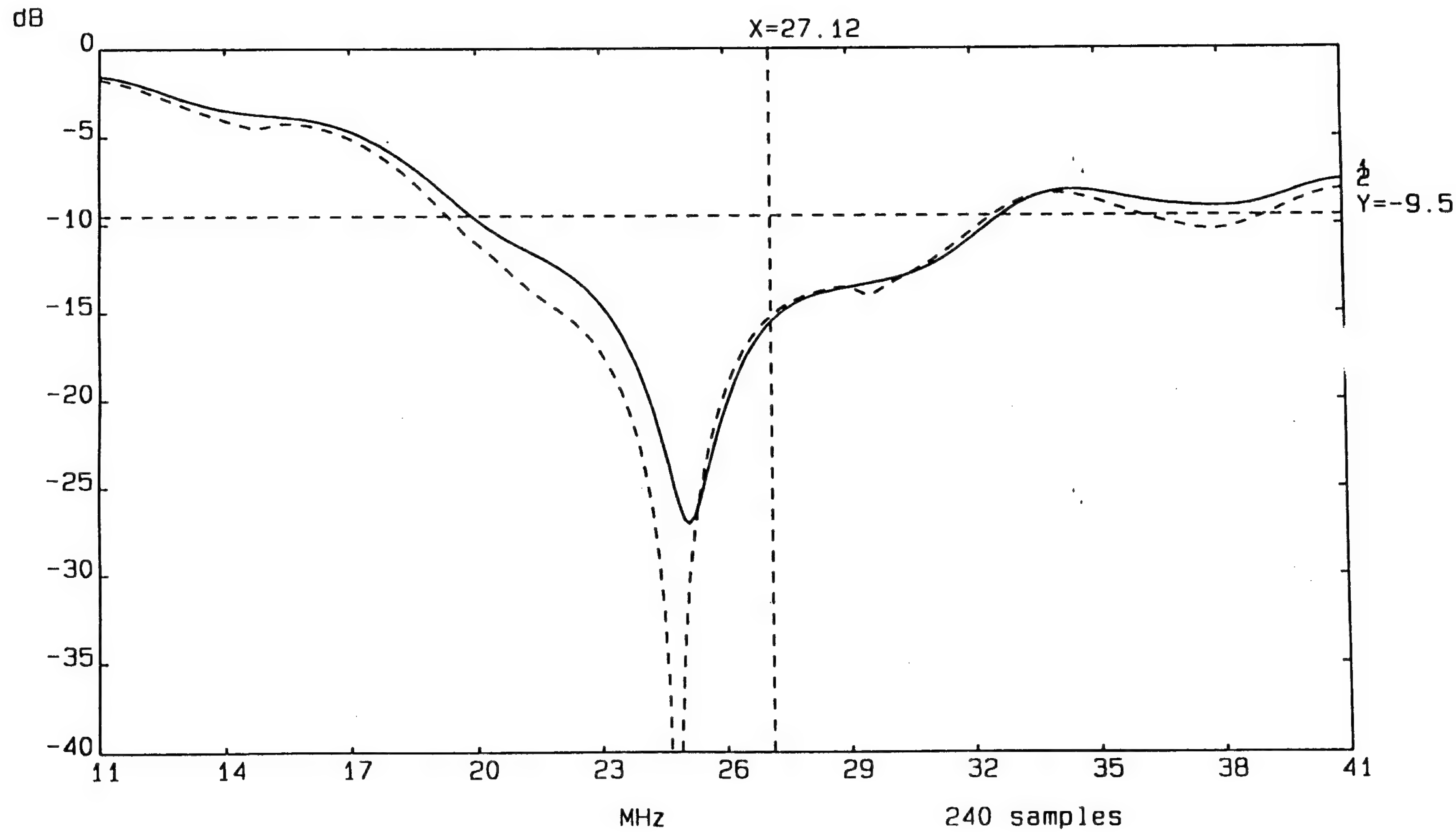
WKAF1002.01L Heat 1 feed A2-pre heat, Return Loss 20-Apr-94 16: 49: 13



Instr=HP3577A, H units=Hz, V units=dB, Npw= 401, VSCL= 10 T1,
Freq MHz= 26, H span MHz= 50, Res KHz= 1, Avg= 1, Wscale= 100,

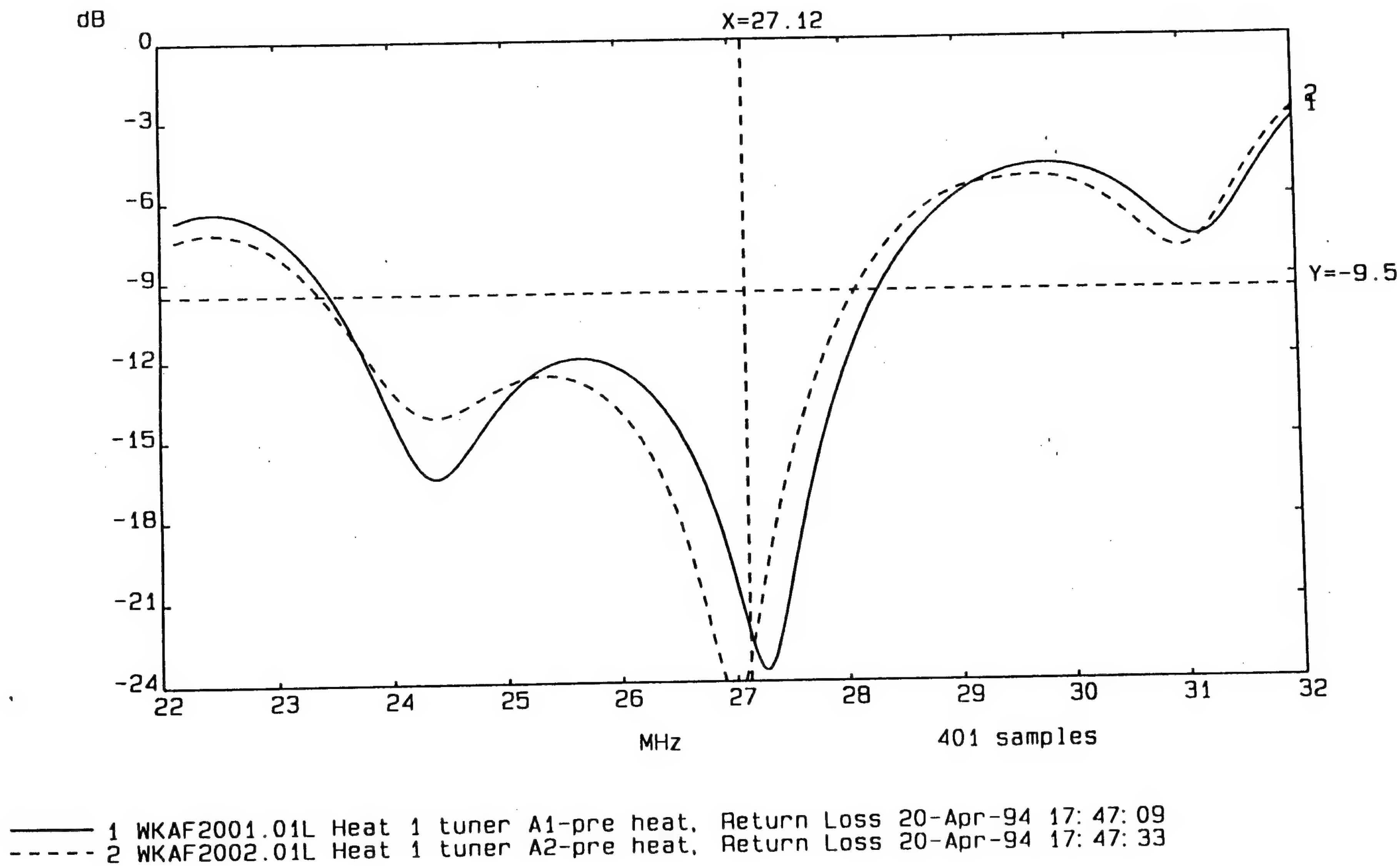
21-May-94

Pre-heat Return Loss Measurements of Applicator #1 (A2) and #2 (A1)



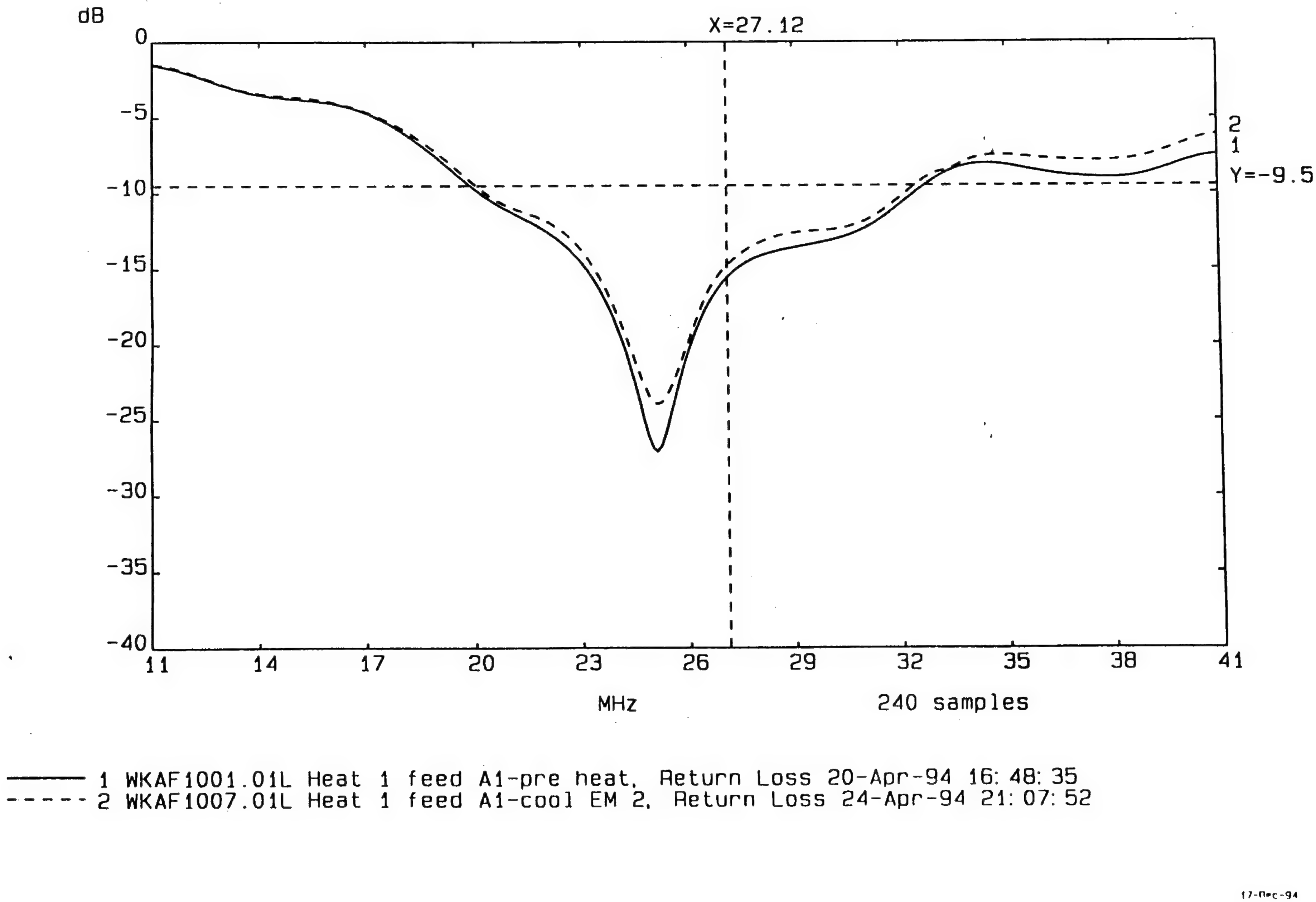
1 WKAF1001.01L Heat 1 feed A1-pre heat, Return Loss 20-Apr-94 16:48:35
2 WKAF1002.01L Heat 1 feed A2-pre heat, Return Loss 20-Apr-94 16:49:13

Pre-heat Return Loss Measurements of Applicator #1 (A2) and #2 (A1) w/tuner

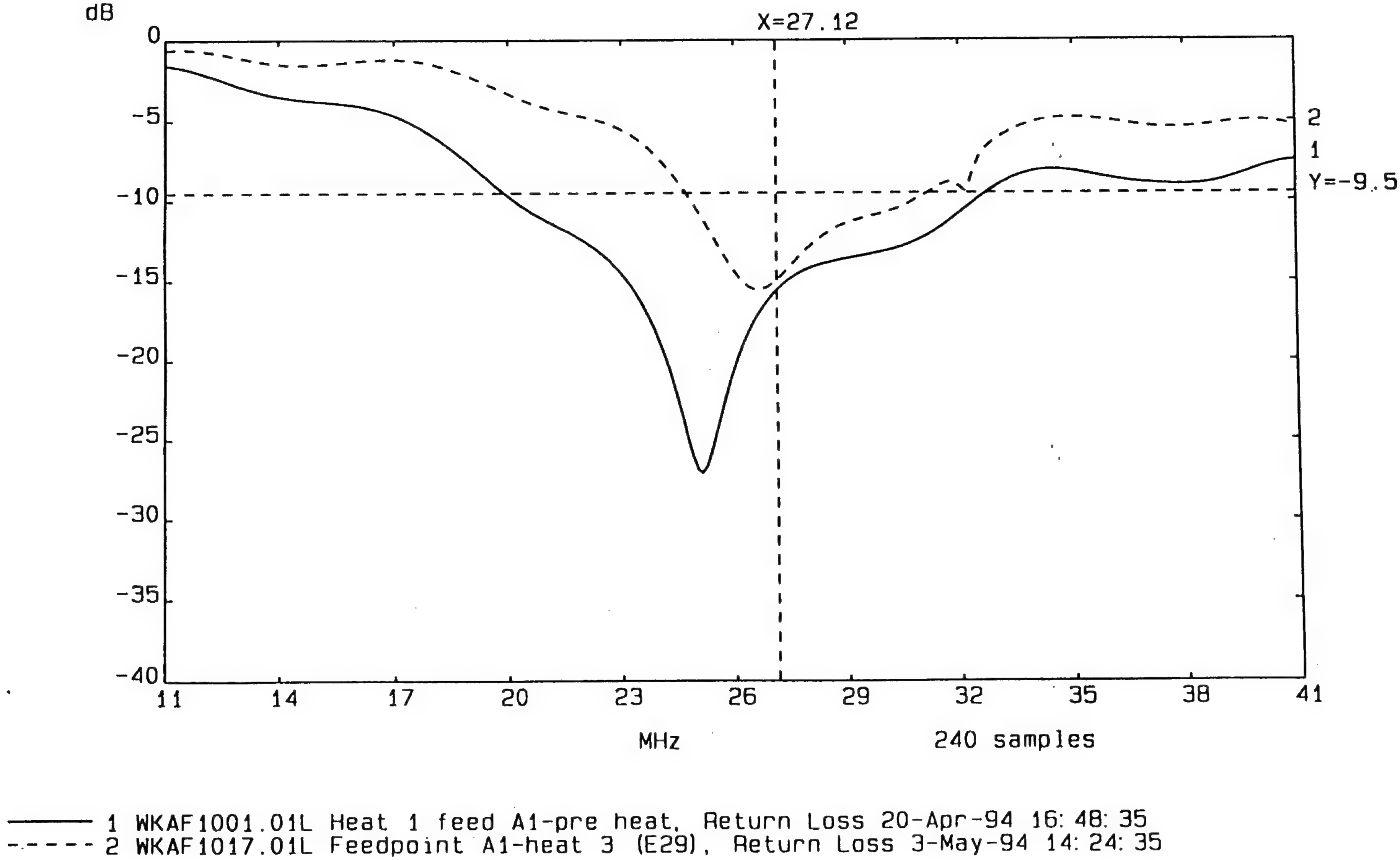


16-Dec-94

Return Loss Measurements of Applicator #1 after 62 KWH of energy to preheat

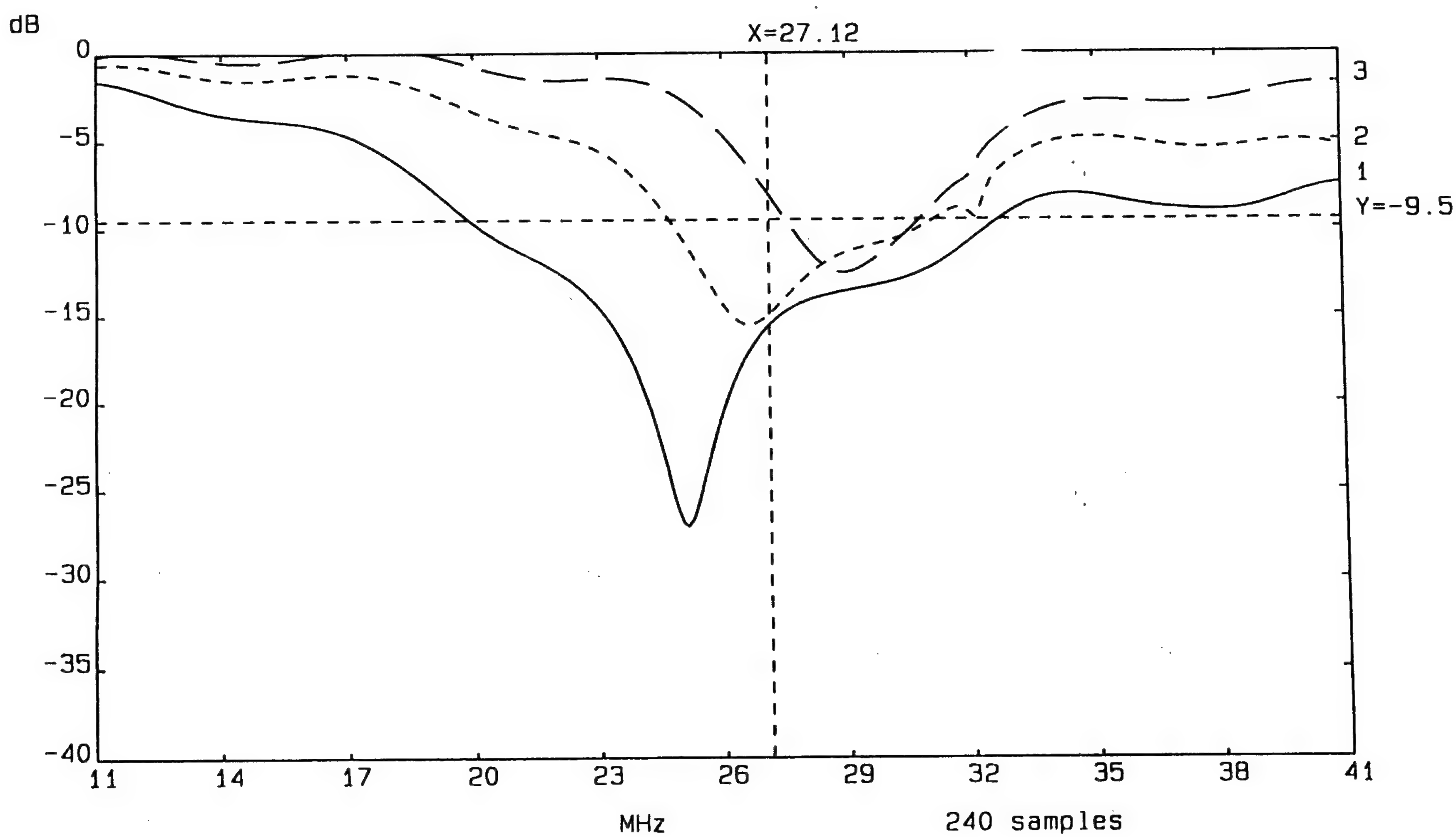


Return Loss comparison of Applicator #1 after over 1700 KWH of energy applied



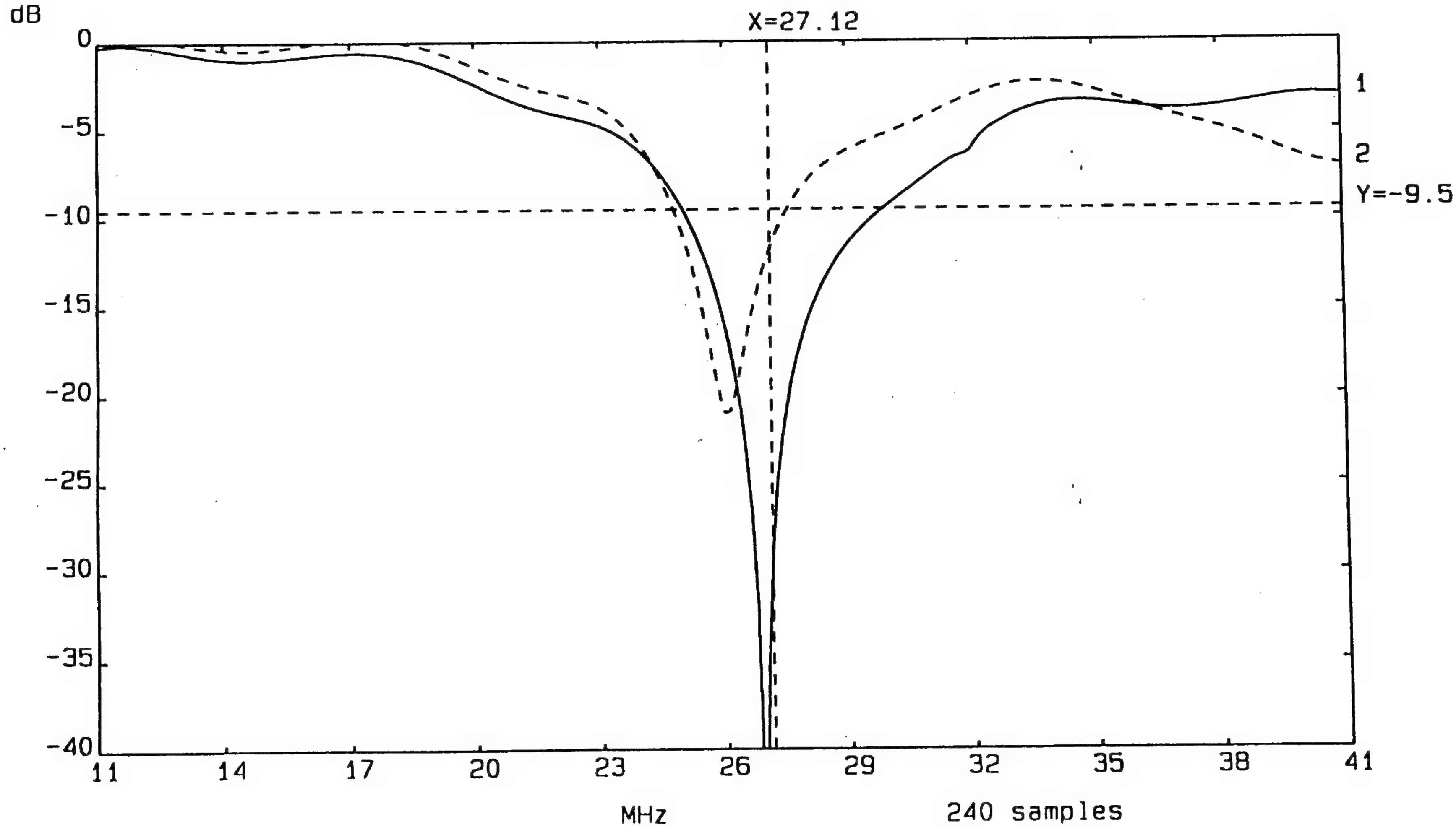
17-Dec-94

Applicator #1 - First heating period



1 WKAF1001.01L Heat 1 feed A1-pre heat, Return Loss 20-Apr-94 16:48:35
2 WKAF1017.01L Feedpoint A1-heat 3 (E29), Return Loss 3-May-94 14:24:35
3 WKAF1107.01L Feedpoint A1-heat 8 (E84), Return Loss 20-May-94 16:54:12

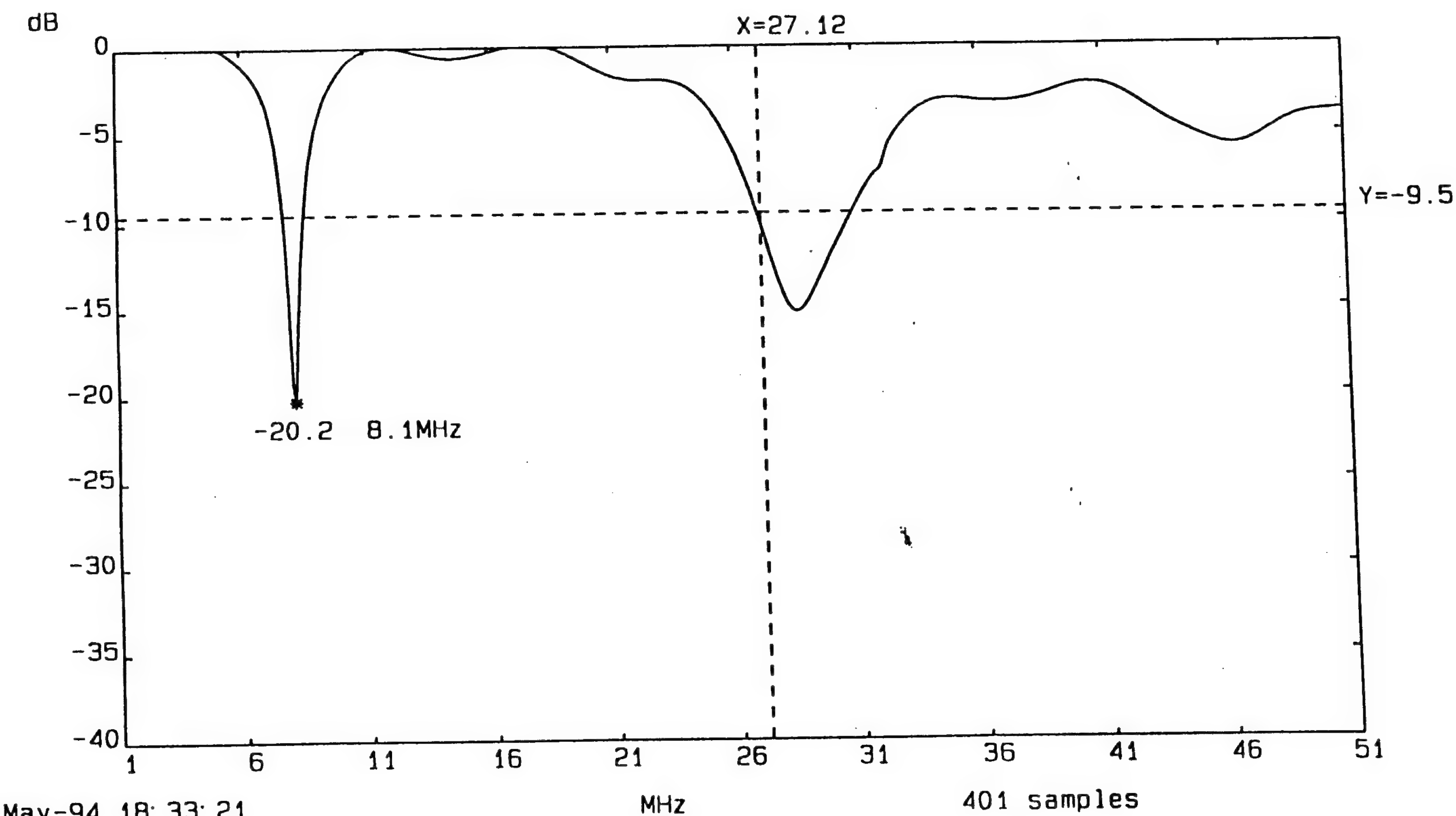
Applicator #1 - Second heating period



1 Wkaf1119.01L Feedpoint A1-heat 11 [E38]. Return Loss 30-May-94 15:57:57
2 WKAF1201.01L Feedpoint A1-heat 14 [E86]. Return Loss 10-Jun-94 18:31:58

17-Dec-94

WKAF1113.01L Feedpoint A1-heat 9 [E93], Return Loss 24-May-94 21: 13: 23



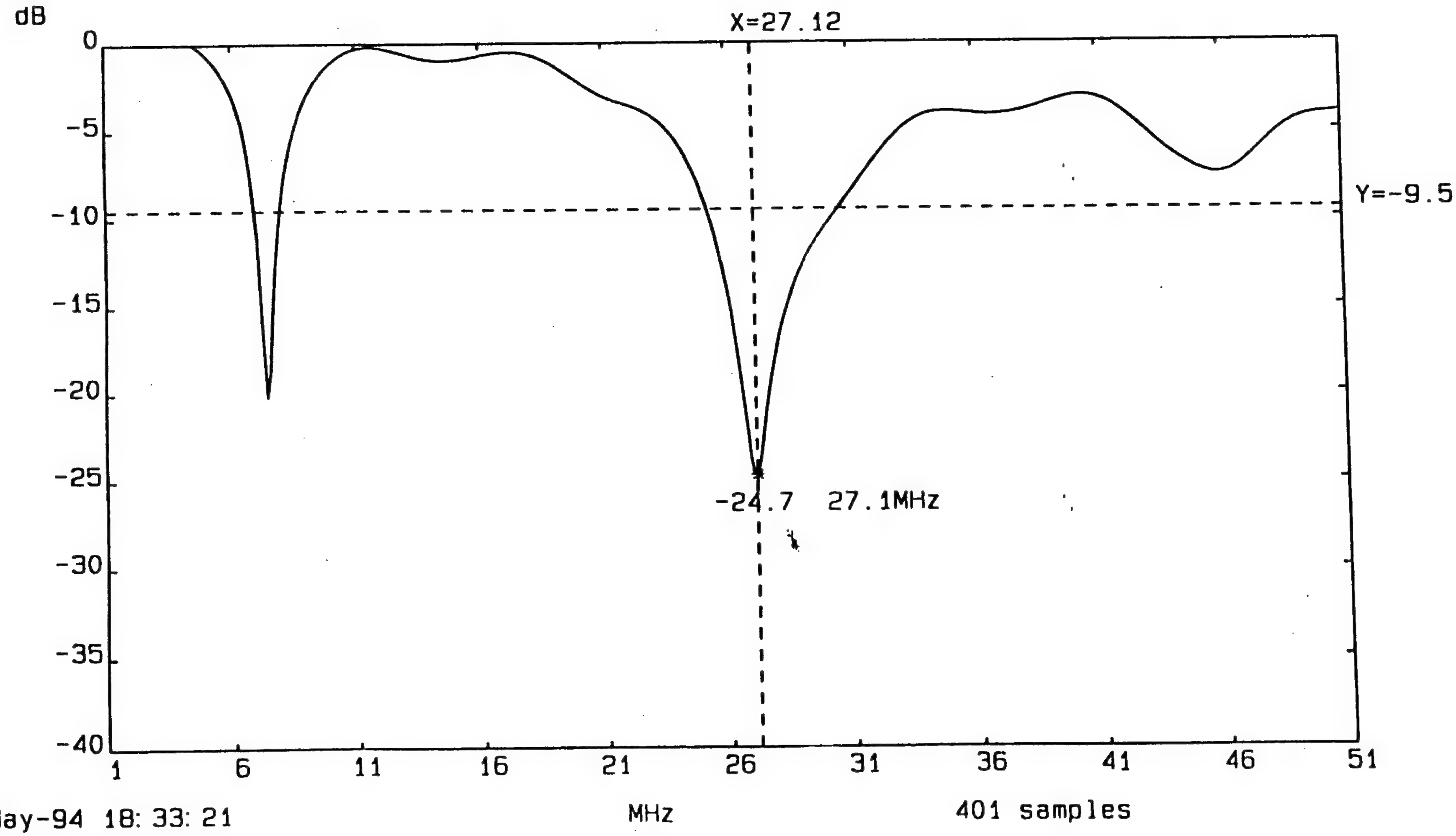
20-May-94 18: 33: 21

401 samples

Instr=HP3577A, H units=Hz, V units=dB, Npw= 401, VSCL= 10 T1,
Freq MHz= 26, H span MHz= 50, Res KHz= 1, Avg= 1, Wscale= 100.

25-May-94

WKAF1114.01L Feedpoint A2-heat 9 [E93], Return Loss 24-May-94 21:12:16

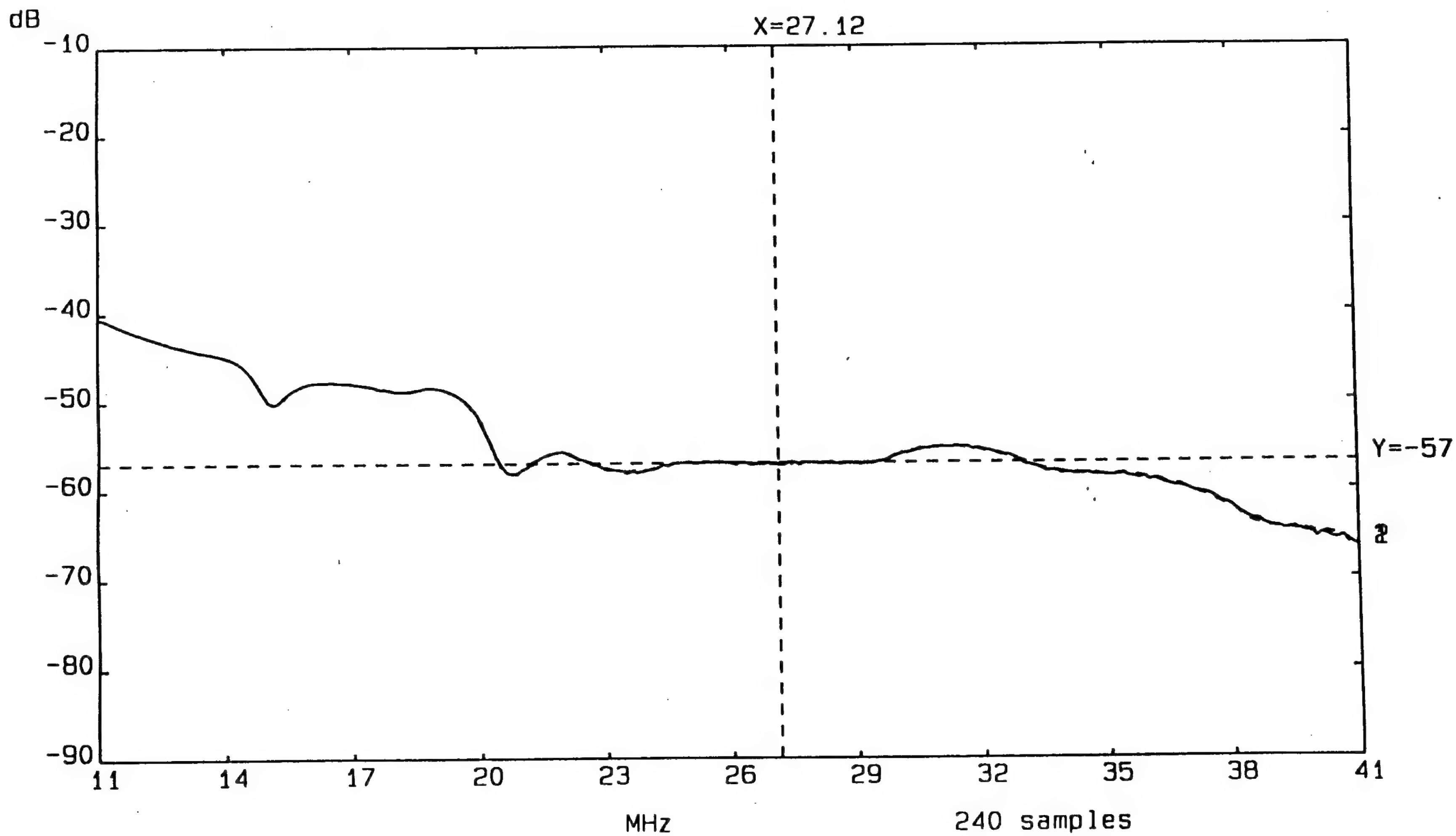


20-May-94 18:33:21

Instr=HP3577A, H units=Hz, V units=dB, Npw= 401, VSCL= 10 T1,
Freq MHz= 26, H span MHz= 50, Res KHz= 1, Avg= 1, Wscale= 100.

25-May-94

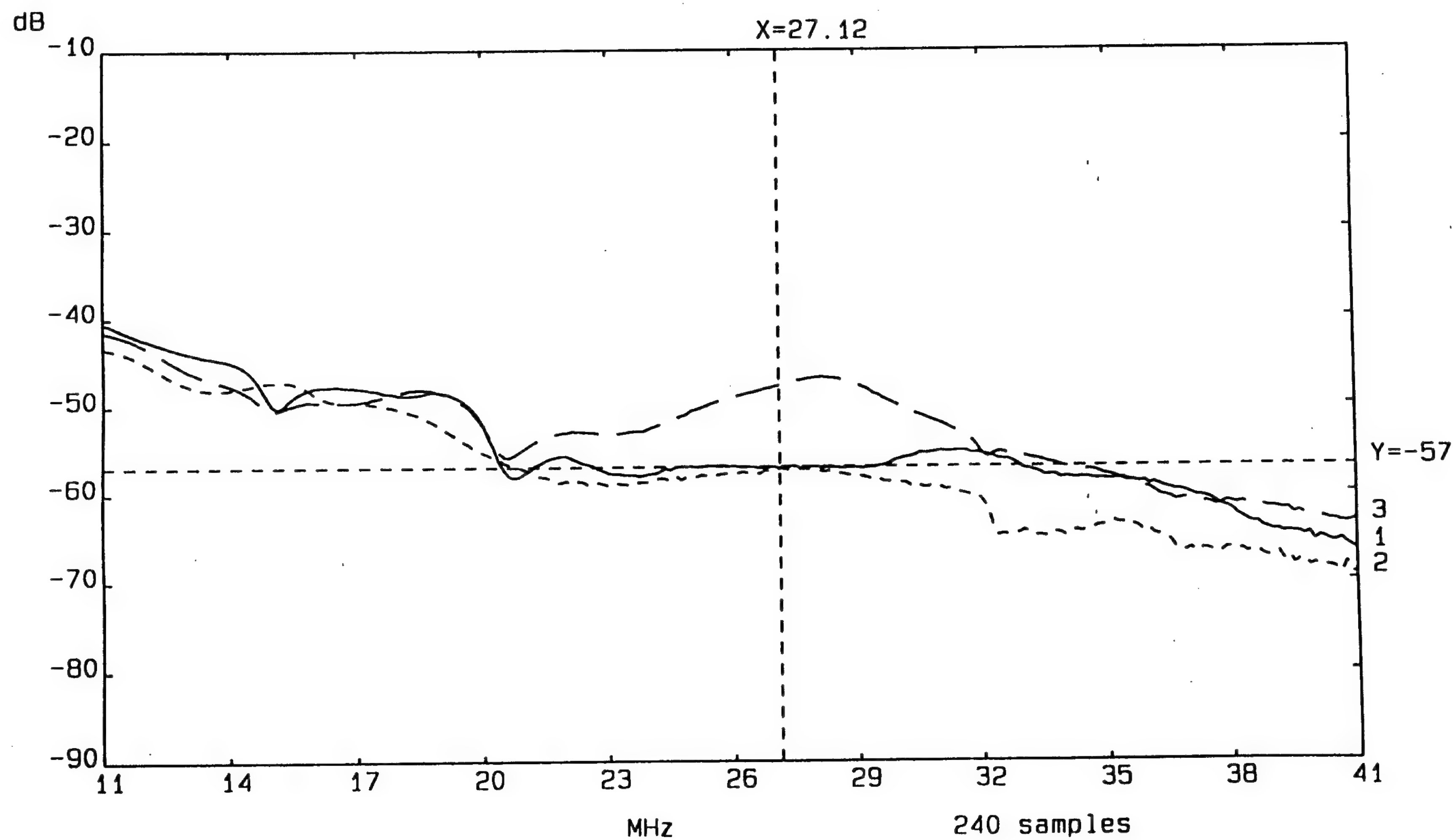
Pre-heat Insert Loss Measurements of Applicator #1 (A2) and #2 (A1)



——— 1 WKAF1001.01K Heat 1 feed A1-pre heat, Insert Loss 20-Apr-94 16: 48: 35
- - - - - 2 WKAF1002.01K Heat 1 feed A2-pre heat, Insert Loss 20-Apr-94 16: 49: 13

16-Dec-94

Applicator #1 - First heating period



1 WKAF1001.01K Heat 1 feed A1-pre heat, Insert Loss 20-Apr-94 16:48:35
2 WKAF1017.01K Feedpoint A1-heat 3 (E29), Insert Loss 3-May-94 14:24:35
3 WKAF1107.01K Feedpoint A1-heat 8 [E84], Insert Loss 20-May-94 16:54:12

17-Dec-94

APPENDIX H - RF System Emission Measurements

RF emission compliance under FCC part 18.301 and surface field strength compliance under (IEEE standard C95.1-1991).

- RF emission measurements

  Measurements for compliance under FCC part 18.305 (b) - Initial submission to USAF WPAFB on 25 April 1994.

  Measurements for compliance under FCC part 18.305 (b) for: 3 May, 18 May, 24 May, 6 June, 7 June, 8 June, and 10 June. Submitted to USAF WPAFB at close of program.

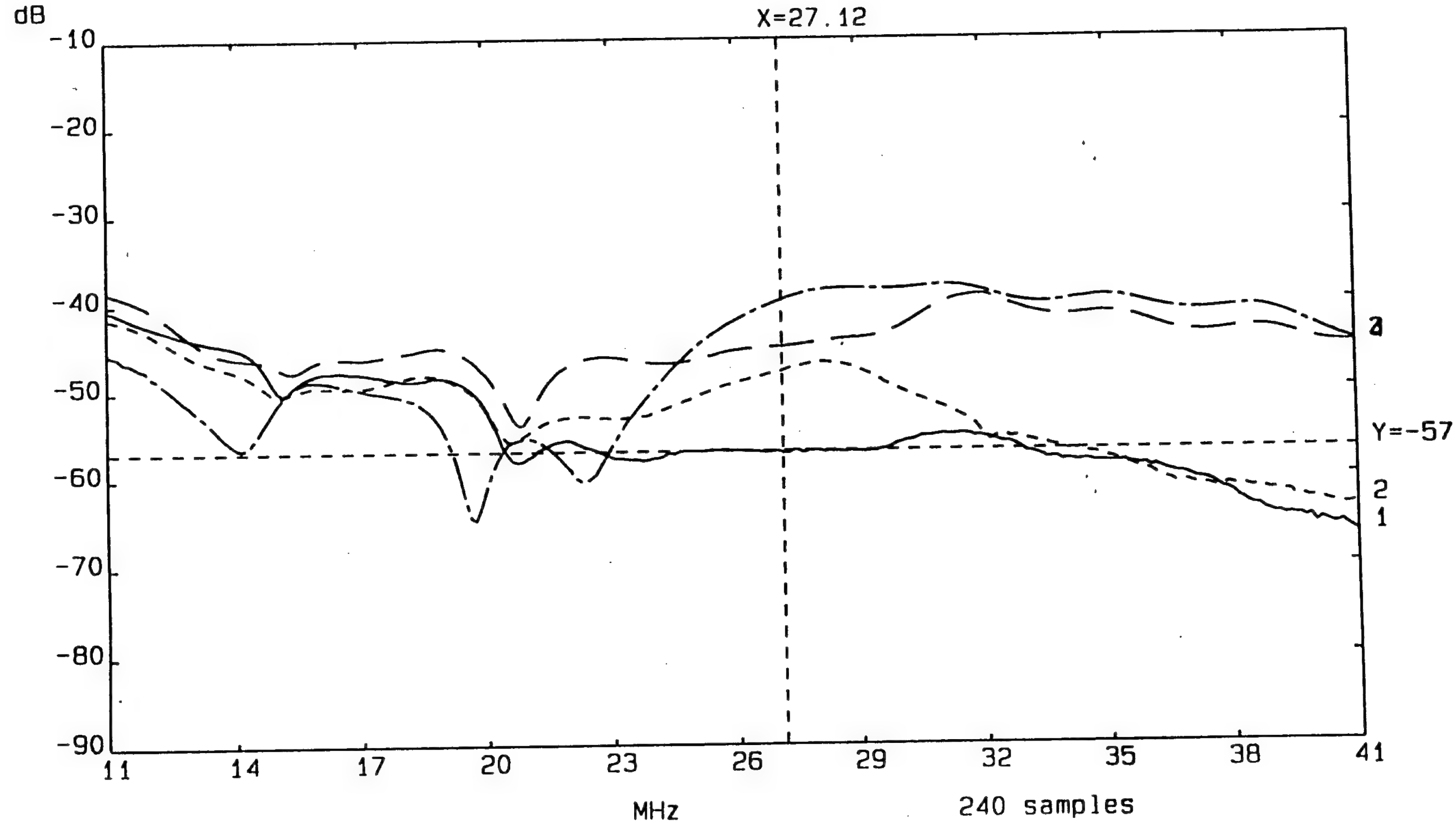
  Plot of Radiated E-Field over 7 to 77 day span - fundamental and harmonics at 300 m
  Plot of Radiated E-Field over 7 to 77 day span - fundamental and harmonics at 10 m and 300 m
  Plot of Radiated E-Field over 7 to 77 day span - fundamental and harmonics at 10 m

- Electric and Magnetic Field Measurements

  Table summary of Isotropic probe safety measurements from 13 April to 9 June 1994.
  Plot of Radiated E-Field over 7 to 77 day span - isotropic probe measurements at 1 m and 3 m

END FILE: KELLYH.A

Applicator #1 to Applicator #2 insertion loss - across entire program



1 WKAF1001.01K Heat 1 feed A1-pre heat. Insert Loss 20-Apr-94 16:48:35
2 WKAF1107.01K Feedpoint A1-heat 8 [E84]. Insert Loss 20-May-94 16:54:12
3 WKAF1123.01K Feedpoint A2-heat 13 [E68]. Insert Loss 7-Jun-94 1:01:41
4 WKAF1201.01K Feedpoint A1-heat 14 [E86]. Insert Loss 10-Jun-94 18:31:58

17-Dec-94

Far field, 300 meter measurements, Part 18.305(b) specific.

The following measurements established a noise floor with a 200 Hz bandwidth & 5 AVG

NOTE: if the signal is not detectable to the noise floor (N.F.) the spectrum analyzer. column is the noise floor level and the field level is corrected to estimate the ambient noi

RF Gen. Power kW	Spectrum Analyzer dBuV	80 ft feed Cable dB attn.	Biconical A.F. cal dB/m	Corrected E-Field dBuV/m	Correcte E-Field uV/m	Measured Freq. MHz	Biconical Location Range & path
13	40.2	0.745	14.1	55.045	565	27.1335	300 m West
13	*-11*	1.01	10	*0.01*	1	54.2685	300 m West
13	*-9.7*	1.234	6.86	*-1.606*	1	81.402	300 m West
13	*-14.19*	1.427	12.91	*0.147*	1	108.5355	300 m West
13	*-11.49*	1.624	13.1	*3.234*	1	135.6685	300 m West
13	*-12.65*	1.761	14.8	*3.911*	2	162.802	300 m West
13	*-13.13*	1.897	16.9	*5.667*	2	189.931	300 m West
	N.F.			*N.F.*			

Note above that harmonics were not detectable
The values listed are the noise floor signal levels o

NOTE: harmonic levels for the 27.12 MHz ISM frequency are to be 169 uV/m or 44.58 dBuV/m. When the power is increased from 13 kW to 23 kW the field values listed above will increase by 2.47 dB.

Far field, 1600 m measurements, Part 18(b)(1) specific.

This measurement is to be performed for full compliance, however, due to the low fundamental and unmeasurable harmonic components observed at the 300 m West site, it is unlikely that significant signal levels will be detected at this point.
NOTE: The allowed harmonic levels for this frequency are not to exceed 10 uV/m which is 20 dBuV/
The fundamental frequency of 27.12 MHz is not predicted to be greater than this level.
Therefore the harmonics are unlikely to be measurable.

NOTE: The 300 m West path is the least electromagnetically obstructed of all of the measurement paths surrounding the test site.

Measurements for compliance under FCC part 18.305 (b)

Kelly AFB, San Antonio TX, RF Heating site S-1
Reference files: TKEL03, labled HEAT 1, EM 3 measurements.
Start: 13:32 on 25 April 1994, Complete 14:45
Measured by : D. Faust, Sgt. Johnson

Measured values that address compliance with FCC regulations are boxed

Frequency: ISM frequency 27.12 MHz +/- 163.0 kHz

ISM Frequency (MHz)		Frequency measured by HP 8591E Sectrum Analyzer.
27.12	Fundamental	27.1335 (-13.5 kHz from center of ISM operating band)
54.24	1st harmonic	54.2685
81.36	2nd harmonic	81.402
108.48	3rd harmonic	108.5355
135.6	4th harmonic	135.6685
162.72	5th harmonic	162.802
189.84	6th harmonic	189.931

Initial Field strength summary after approximately 14 hours of heating time.
Measured with: EMCO 3104C Biconical antenna, vertical polarization at 2 m height and HP 8591E spectrum analyzer w/EMC measurement option.

Near field 10 meter measurements - baseline for harmonic attenuation measurements.
Measurement of fundamental & harmonics w/ 9 kHz EMI bandwidth w/100 AVG

RF Gen. Power kW	Spectrum Analyzer dBuV	80 ft feed Cable dB attn.	Biconical A.F. cal dB/m	Corrected E-Field dBuV/m	Correcte E-Field uV/m	Measured Freq. MHz	Biconical Location Range & path
13	95.2	0.745	14.1	110.045	317,870	27.1335	10 m East
13	19.45	1.01	10	30.46	33	54.2685	10 m East
13	44.6	1.234	6.86	52.694	431	81.402	10 m East
13	23.45	1.427	12.91	37.787	78	108.5355	10 m East
13	34.5	1.624	13.1	49.224	289	135.6685	10 m East
13	34.8	1.761	14.8	51.361	370	162.802	10 m East
13	16.5	1.897	16.9	35.297	58	189.931	10 m East
13	95.65	0.745	14.1	110.495	334,773	27.1335	10m South
13	22.8	1.01	10	33.81	49	54.2685	10m South
13	46.4	1.234	6.86	54.494	531	81.402	10m South
13	26.2	1.427	12.91	40.537	106	108.5355	10m South
13	23.45	1.624	13.1	38.174	81	135.6685	10m South
13	39.19	1.761	14.8	55.751	613	162.802	10m South
13	11.38	1.897	16.9	30.177	32	189.931	10m South
13	84.5	0.745	14.1	99.345	92,736	27.1335	10 m North
13	21.9	1.01	10	32.91	44	54.2685	10 m North
13	47.1	1.234	6.86	55.194	575	81.402	10 m North
13	19	1.427	12.91	33.337	46	108.5355	10 m North
13	27.4	1.624	13.1	42.124	128	135.6685	10 m North
13	34.4	1.761	14.8	50.961	353	162.802	10 m North
13	35.12	1.897	16.9	53.917	496	189.931	10 m North

Date of Measurement	**Wednesday, May 24, 1994, 21:57**
Data logging file name	TKEL10
Measurements by:	David L. Faust, KAI

Near field 10 meter measurements **Applicator #2**

Measurement of fundamental & harmonics w/ 9 kHz EMI bandwidth w/100 AVG

RF Gen. Power kW	Spectrum Analyzer dBuV	80 ft feed Cable dB attn.	Biconical A.F. cal dB/m	Corrected E-Field dBuV/m	Corrected E-Field uV/m	Measured Freq. MHz	Biconical Location Range & path
21.5	95.65	0.745	14.1	110.495	334,773	27.1343	10 m East
21.5	34.82	1.01	10	45.83	196	54.2675	10 m East
21.5	45.01	1.234	6.86	53.104	452	81.402	10 m East
21.5	38.96	1.427	12.91	53.297	462	108.5345	10 m East
21.5	45.85	1.624	13.1	60.574	1,068	135.6683	10 m East
21.5	50	1.761	14.8	66.561	2,128	162.8018	10 m East
21.5	49.27	1.897	16.9	68.067	2,531	189.9353	10 m East

Vector Voltmeter reading w/70 dB coupler

109.5 dBuV Forward + 70 dB coupling factor

dBuV Reverse + 70 dB coupling factor

Date of Measurement	**Monday, June 6, 1994, 21:23**
Data logging file name	TKEL13
Measurements by:	D. Faust

Near field 10 meter measurements **Applicator #1**

Measurement of fundamental & harmonics w/ 9 kHz EMI bandwidth w/100 AVG

RF Gen. Power kW	Spectrum Analyzer dBuV	80 ft feed Cable dB attn.	Biconical A.F. cal dB/m	Corrected E-Field dBuV/m	Corrected E-Field uV/m	Measured Freq. MHz	Biconical Location Range & path
23.57	105.27	0.745	14.1	120.115	1,013,328	27.1343	10 m East
23.57	40.35	1.01	10	51.36	370	54.2685	10 m East
23.57	40.68	1.234	6.86	48.774	275	81.402	10 m East
23.57	31.76	1.427	12.91	46.097	202	108.5355	10 m East
23.57	34.3	1.624	13.1	49.024	283	135.6685	10 m East
23.57	30.09	1.761	14.8	46.651	215	162.802	10 m East
23.57	30.57	1.897	16.9	49.367	294	189.931	10 m East

Vector Voltmeter reading of applicator transmission line w/70 dB coupler

109.9 dBuV Forward + 70 dB coupling factor

101.6 dBuV Reverse + 70 dB coupling factor

Measurements for compliance under FCC part 18.305 (b)

Continued Electromagnetic Emission Monitoring

RF Heating site S-1

Kelly AFB, TX

Date of Measurement	**Tuesday May 3, 1994, 14:01**
Data logging file name:	TKEL04
Measurements by:	David L. Faust, KAI Technologies Inc.

Near field 10 meter measurements **Applicator #1**

Measurement of fundamental & harmonics w/ 9 kHz EMI bandwidth w/100 AVG

RF Gen. Power kW	**Spectrum Analyzer** dBuV	**80 ft feed Cable** dB attn.	**Biconical A.F. cal** dB/m	**Corrected E-Field** dBuV/m	**Corrected E-Field** uV/m	**Measured Freq.** MHz	**Biconical Location** Range & path
18.58	99.82	0.745	14.1	114.665	541.066	27.1345	10 m East
18.58	32.7	1.01	10	43.71	153	54.2683	10 m East
18.58	47.2	1.234	6.86	55.294	582	81.401	10 m East
18.58	32.4	1.427	12.91	46.737	217	108.5355	10 m East
18.58	42.56	1.624	13.1	57.284	731	135.6685	10 m East
18.58	45.2	1.761	14.8	61.761	1,225	162.802	10 m East
18.58	15.8	1.897	16.9	34.597	54	189.931	10 m East

Date of Measurement	**Wednesday, May 18, 1994, 18:31**
Data logging file name:	TKEL08
Measurements by:	David L. Faust, KAI Technologies Inc.

Near field 10 meter measurements **Applicator #1**

Measurement of fundamental & harmonics w/ 9 kHz EMI bandwidth w/100 AVG

RF Gen. Power kW	**Spectrum Analyzer** dBuV	**80 ft feed Cable** dB attn.	**Biconical A.F. cal** dB/m	**Corrected E-Field** dBuV/m	**Corrected E-Field** uV/m	**Measured Freq.** MHz	**Biconical Location** Range & path
20	102.7	0.745	14.1	117.545	753.789	27.135	10 m East
20	39.64	1.01	10	50.65	341	54.2685	10 m East
20	37.35	1.234	6.86	45.444	187	81.402	10 m East
20	31.94	1.427	12.91	46.277	206	108.5355	10 m East
20	40	1.624	13.1	54.724	545	135.6685	10 m East
20	39	1.761	14.8	55.561	600	162.802	10 m East
20	30.46	1.897	16.9	49.257	290	189.931	10 m East

Vector Voltmeter reading w/70 dB coupler

108.1 dBuV Forward + 70 dB coupling factor

100.4 dBuV Reverse + 70 dB coupling factor

Date of Measurement — Monday, June 10, 1994, 00:05
Data logging file name — TKEL14
Measurements by: — D. Faust

Near field 10 meter measurements **Applicator #1**

Measurement of fundamental & harmonics w/ 9 kHz EMI bandwidth w/100 AVG

RF Gen. Power kW	Spectrum Analyzer dBuV	80 ft feed Cable dB attn.	Biconical A.F. cal dB/m	Corrected E-Field dBuV/m	Corrected E-Field uV/m	Measured Freq. MHz	Biconical Location Range & path
23	93.2	0.745	14.1	108.045	252,493	27.1348	10 m East
23	31.03	1.01	10	42.04	126	54.2684	10 m East
23	53.49	1.234	6.86	61.584	1,200	81.4046	10 m East
23	43.3	1:427	12.91	57.637	762	108.5396	10 m East
23	43.75	1.624	13.1	58.474	839	135.6689	10 m East
23	40.9	1.761	14.8	57.461	747	162.8028	10 m East
23	29.89	1.897	16.9	48.687	272	189.9358	10 m East

Vector Voltmeter reading of applicator transmission line w/70 dB coupler

dBuV Forward + 70 dB coupling factor

dBuV Reverse + 70 dB coupling factor

Date of Measurement **Friday, June 10, 1994, 13:48**
Data logging file name TKEL14
Measurements by: David L. Faust, KAI Technologies Inc.
TSGT James Lewis, 651 CCSG/SCSML Kelly AFB

Near field 10 meter measurements **Applicator #1**
Measurement of fundamental & harmonics w/ 9 kHz EMI bandwidth w/100 AVG

RF Gen. Power kW	Spectrum Analyzer dBuV	80 ft feed Cable dB attn.	Biconical A.F. cal dB/m	Corrected E-Field dBuV/m	Corrected E-Field uV/m	Measured Freq. MHz	Biconical Location Range & path
20	99.75	0.745	14.1	114.595	536.723	27.1343	10 m East
20	37.45	1.01	10	48.46	265	54.2685	10 m East
20	56.85	1.234	6.86	64.944	1,767	81.402	10 m East
20	36.65	1.427	12.91	50.987	354	108.5355	10 m East
20	35.9	1.624	13.1	50.624	340	135.6685	10 m East
20	33.89	1.761	14.8	50.451	333	162.802	10 m East
20	29.82	1.897	16.9	48.617	270	189.931	10 m East

Vector Voltmeter reading of applicator transmission line w/70 dB coupler
109.2 dBuV Forward + 70 dB coupling factor
dBuV Reverse + 70 dB coupling factor

Far field, 300 meter measurements, Part 18.305(b) specific.
The following measurements established a noise floor with a 200 Hz bandwidth & 5 AVG
NOTE: A harmonic signal was not detectable to the noise floor (N.F.) of these settings.
The corrected field levels estimate the strength of the ambient noise.

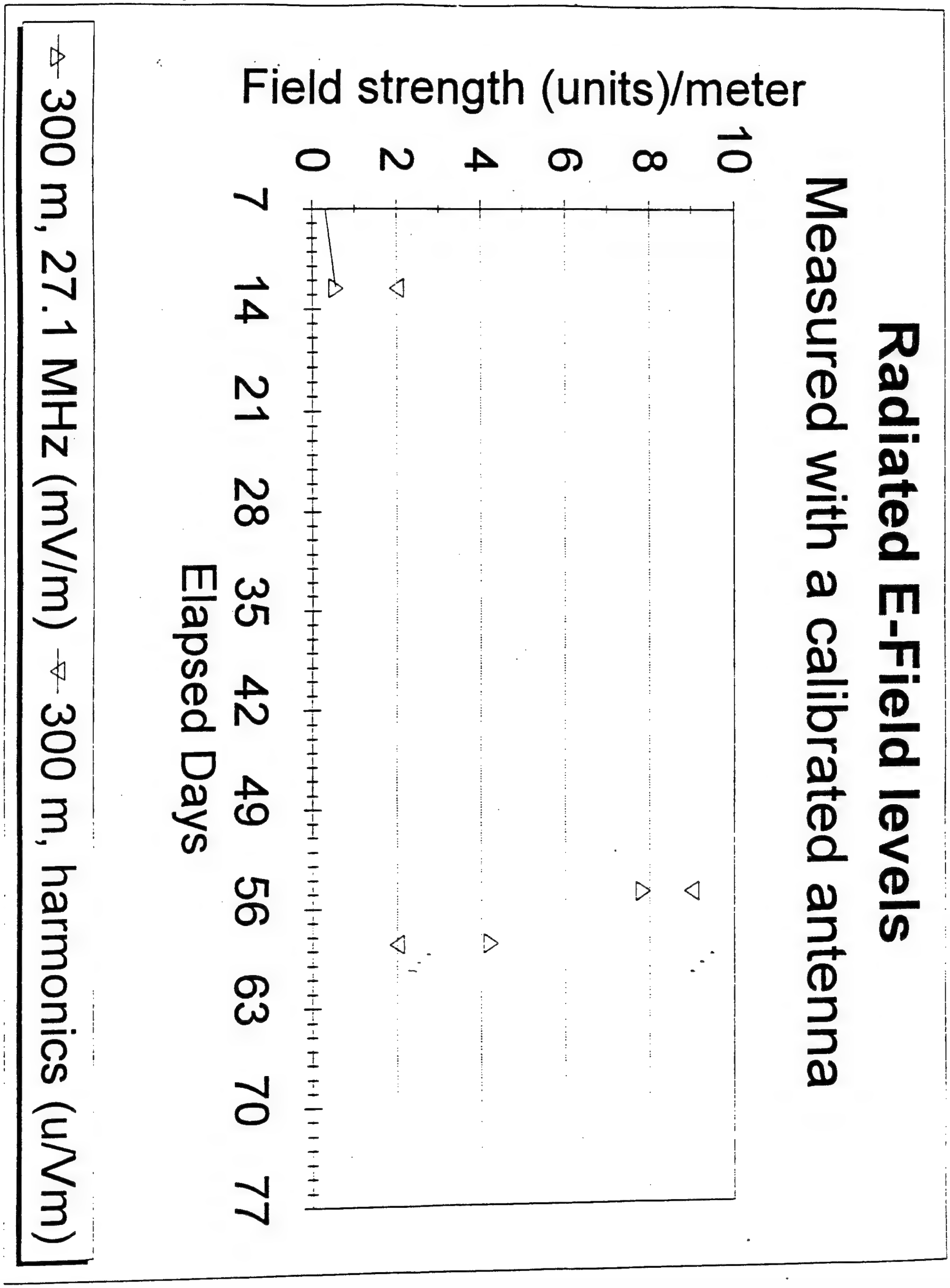
RF Gen. Power kW	Spectrum Analyzer dBuV	80 ft feed Cable dB attn.	Biconical A.F. cal dB/m	Corrected E-Field dBuV/m	Corrected E-Field uV/m	Measured Freq. MHz	Biconical Location Range & path
20	57.7	0.745	14.1	72.545	4,239	27.1343	300 m West
20	*-11.8*	1.01	10	*-0.79*	1	54.26865	300 m West
20	*-12.64*	1.234	6.86	*-4.546*	1	81.4011	300 m West
20	*-14.32*	1.427	12.91	*0.017*	1	108.5372	300 m West
20	*-14.39*	1.624	13.1	*0.334*	1	135.6715	300 m West
20	*-13.29*	1.761	14.8	*3.271*	1	162.94	300 m West
20	*-13.75*	1.897	16.9	*5.047*	2	189.9356	300 m West
	N.F.			*N.F. - no detectable harmonics*			

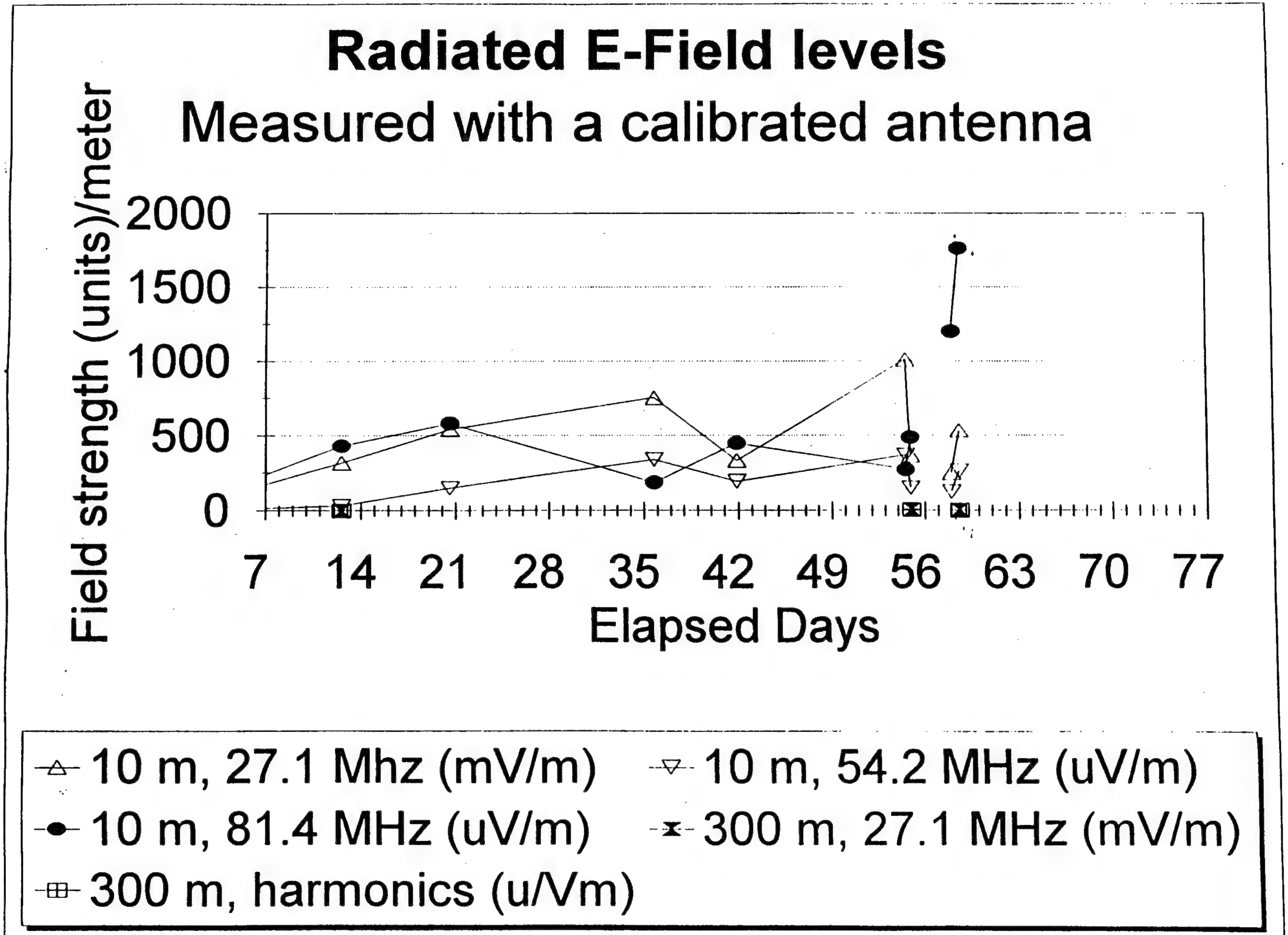
Vector Voltmeter reading of applicator transmission line w/70 dB coupler
109.9 dBuV Forward + 70 dB coupling factor
101.6 dBuV Reverse + 70 dB coupling factor

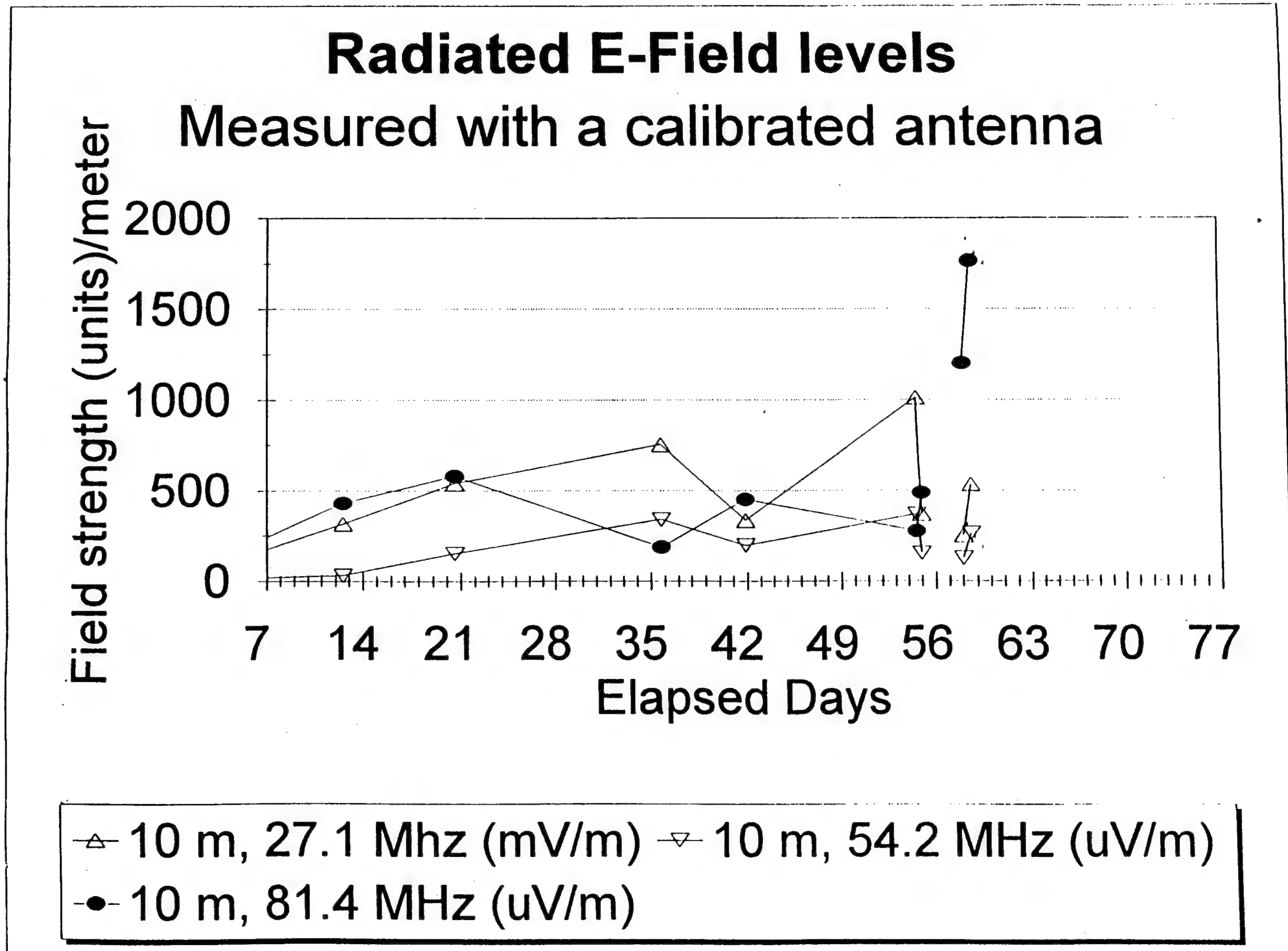
+++ END OF RF HEATING PROGRAM +++

SUMMARY

Corrected measurements suggest that that both applicators at power levels up to 25 kW operated within FCC part !8.305 (b) requirements.

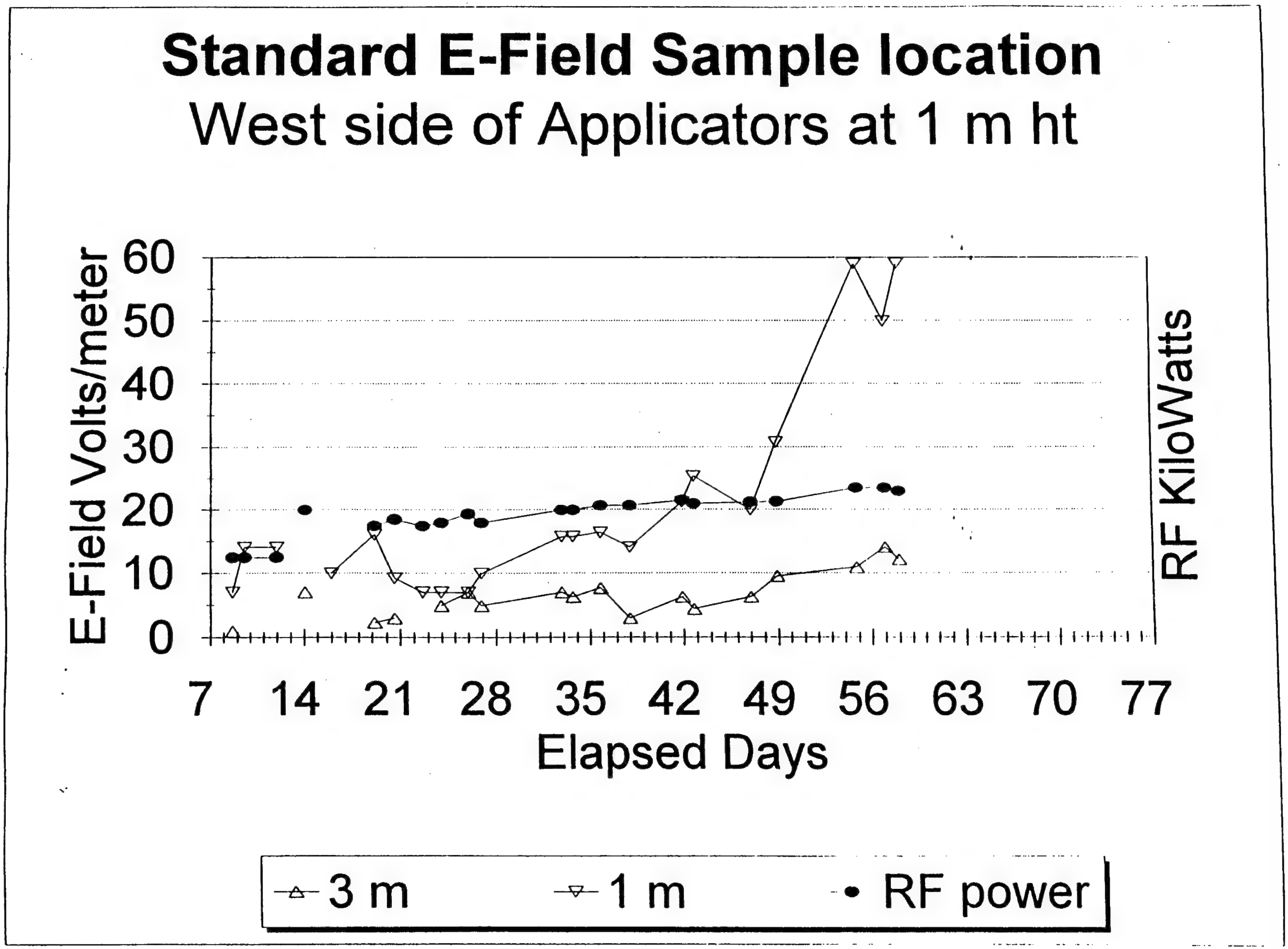

Radiated E-Field levels
Measured with a calibrated antenna
Field strength (units)/meter
0
2
4
6
8
10
7
14
21
28
35
42
49
56
63
70
77
Elapsed Days
300 m, 27.1 MHz (mV/m)
300 m, harmonics (u/Vm)


Radiated E-Field levels
Measured with a calibrated antenna
Field strength (units)/meter
2000
1500
1000
500
0
7
14
21
28
35
42
49
56
63
70
77
Elapsed Days
10 m, 27.1 Mhz (mV/m)
10 m, 54.2 MHz (uV/m)
10 m, 81.4 MHz (uV/m)
300 m, 27.1 MHz (mV/m)
300 m, harmonics (u/Vm)

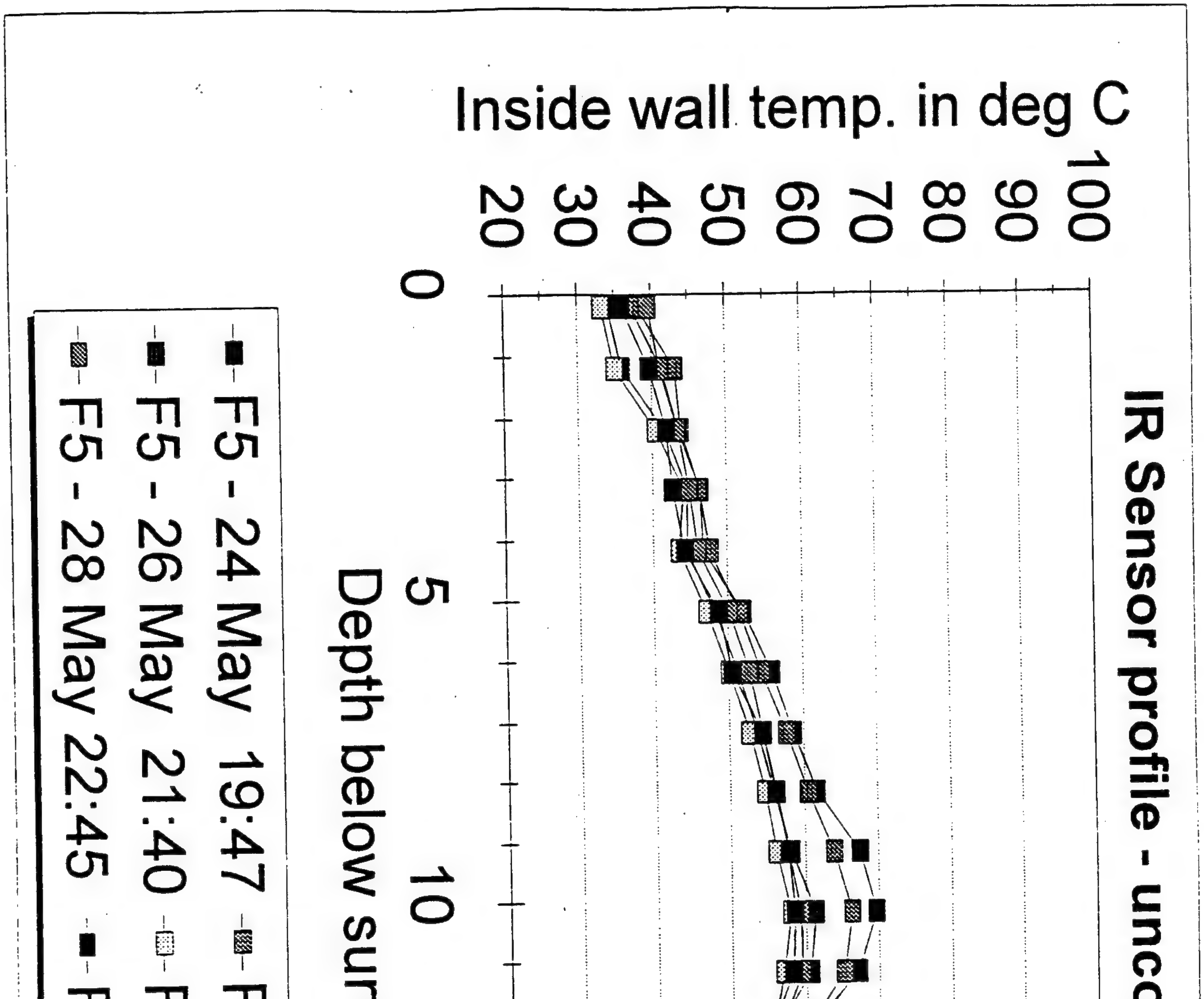

Radiated E-Field levels
Measured with a calibrated antenna
Field strength (units)/meter
2000
1500
1000
500
0
7
14
21
28
35
42
49
56
63
70
77
Elapsed Days
10 m, 27.1 Mhz (mV/m)
10 m, 54.2 MHz (uV/m)
10 m, 81.4 MHz (uV/m)

Isotropic Probe Safety Measuremet
Holiday

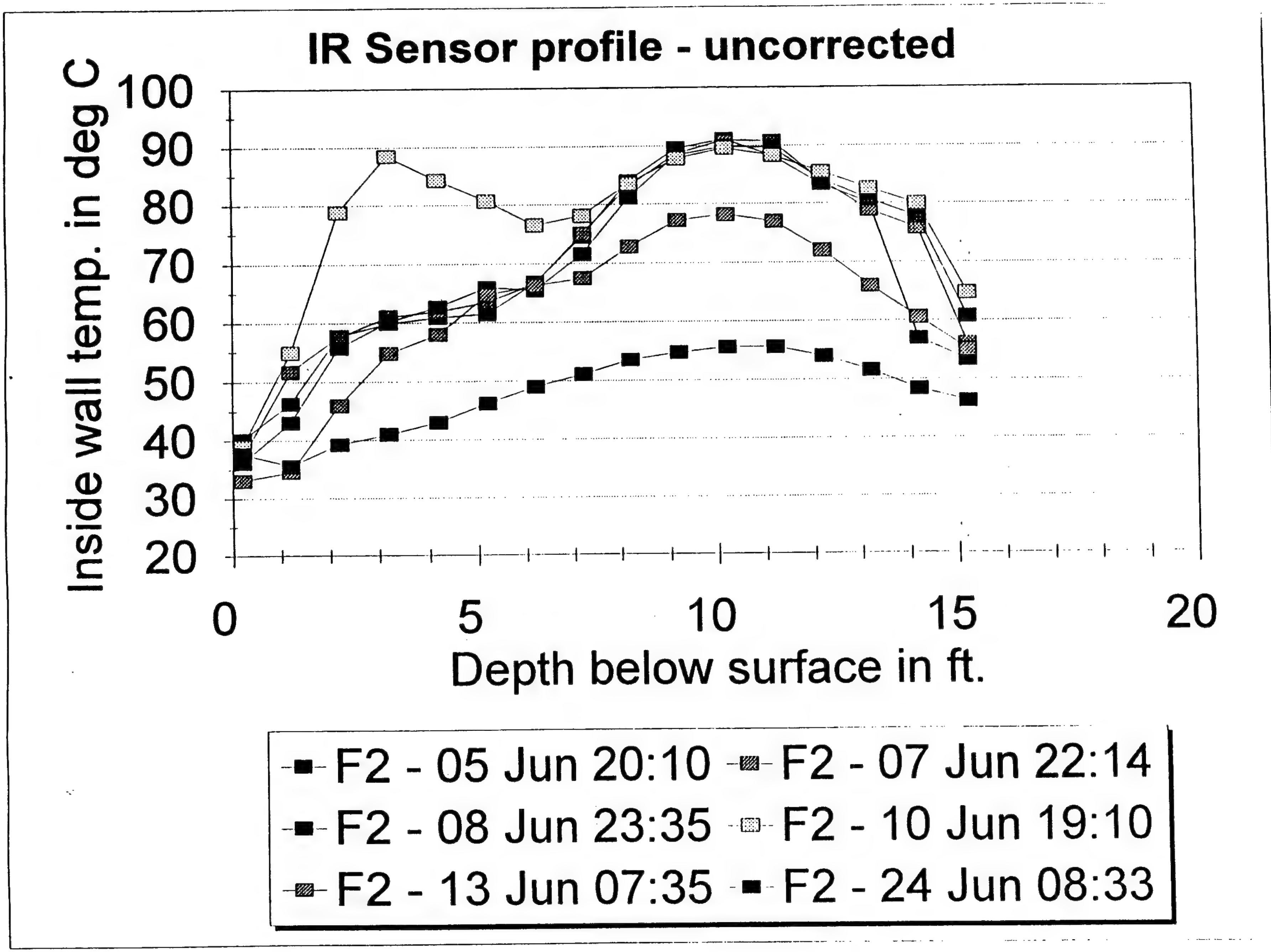
Date	Time	RF power	Standard measurement locations @ 1 m ht to West				
			3 m	1 m	contact	Location	Applicator
		KiloWatts	V/M	V/M	V/M		
13-Apr-94	12:00 AM						
21-Apr-94	03:44 PM	12.5	1	7	25		
22-Apr-94	01:00 PM	12.5		14.1	63.24	A2	Ant. 1
24-Apr-94	11:30 PM	12.5		14.1	63.24	A2	Ant. 1
25-Apr-94	10:16 AM	13					
27-Apr-94	01:37 AM	20	7		50	A2	Ant. 1
28-Apr-94	11:45 PM	18		10		A2	Ant. 1
02-May-94	03:12 AM	17.5	2.3	16.1	81.24	A2	Ant. 1
03-May-94	02:01 PM	18.5	3	9.2	77.45	A2	Ant. 1
05-May-94	02:47 PM	17.5		7	86.6	A2	
06-May-94	11:25 PM	18	5	7	77.45	A2	
08-May-94	11:02 PM	19.4	7	7	77.45	A2	
09-May-94	10:15 PM	18	5	10	77.45	A2	
15-May-94	08:10 PM	20	7	15.8	100	A2	
16-May-94	05:00 PM	20	6.3	15.8	132.28	A2	
18-May-94	06:31 PM	20.7	7.7	16.43	77.4	A2	
20-May-94	11:54 PM	20.7	3	14.1	44.72	A1	Ant. 2
24-May-94	09:48 PM	21.5	6.3	21.2	31.62	A1	Ant. 2
25-May-94	06:36 PM	21	4.4	25.4	50	A1	Ant. 2
30-May-94	12:27 AM	21.2	6.3	20	59.1	A1	Ant. 2
31-May-94	10:25 PM	21.3	9.5	30.8	54.7	A2	Ant. 1
06-Jun-94	08:50 PM	23.5	10.9	59	70.7	A2	Ant. 1
08-Jun-94	11:12 PM	23.5	14.1	50	89.4	A2	Ant. 1
09-Jun-94	11:23 PM	23	12.2	59.1	94.8	A2	Ant. 1

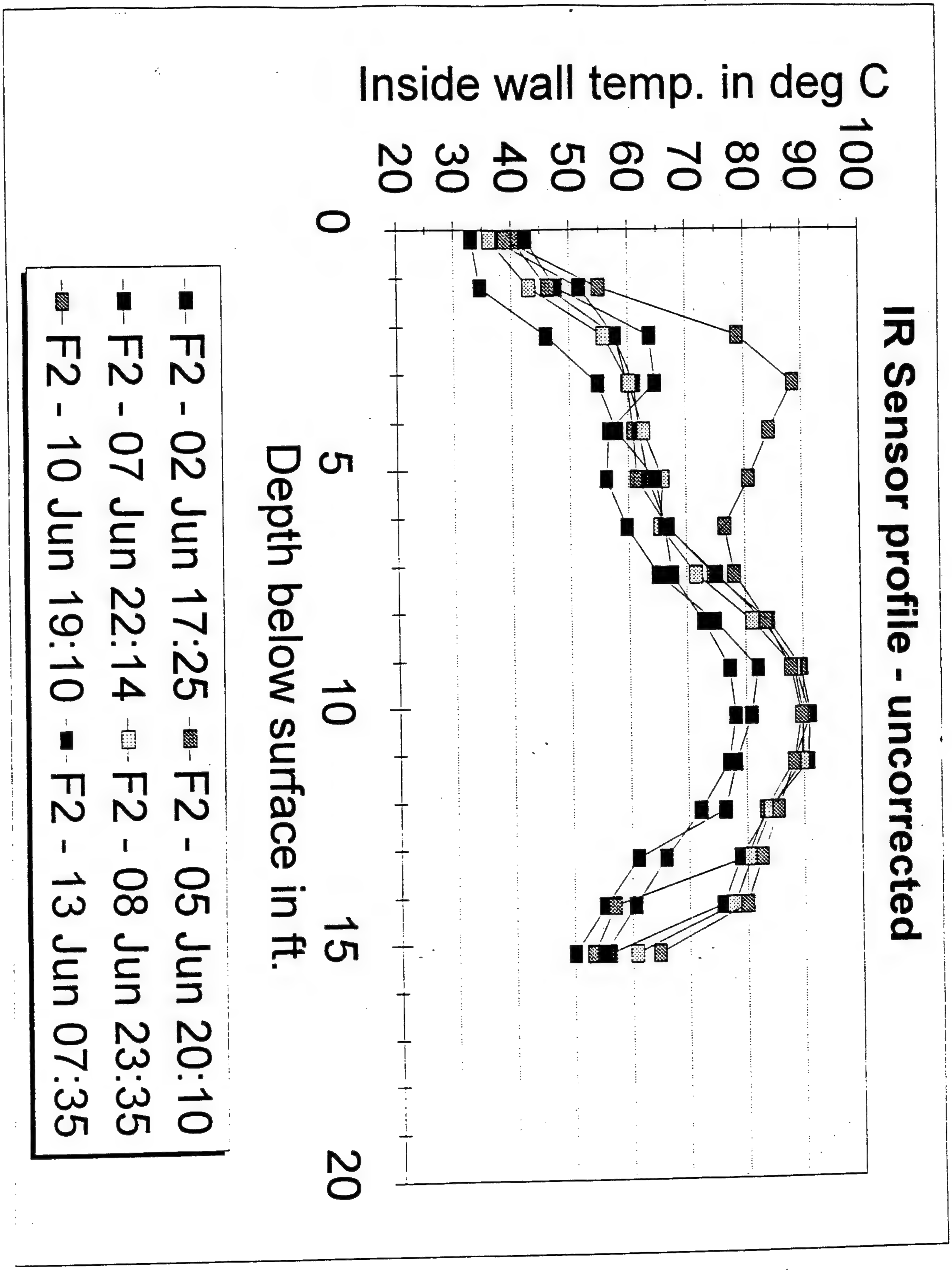


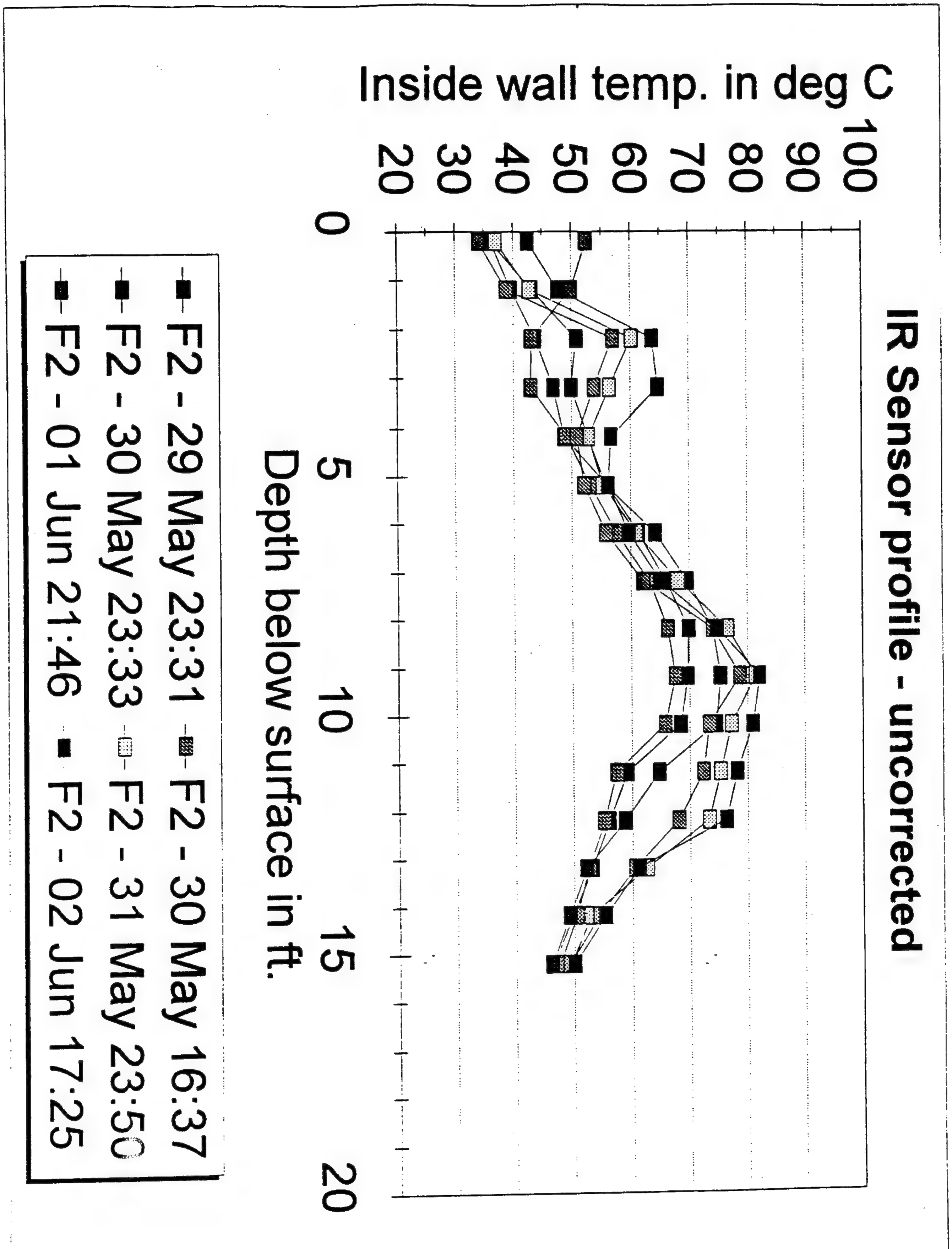
Standard E-Field Sample location
West side of Applicators at 1 m ht
E-Field Volts/meter
0
10
20
30
40
50
60
RF KiloWatts
7
14
21
28
35
42
49
56
63
70
77
Elapsed Days
3 m
1 m
RF power

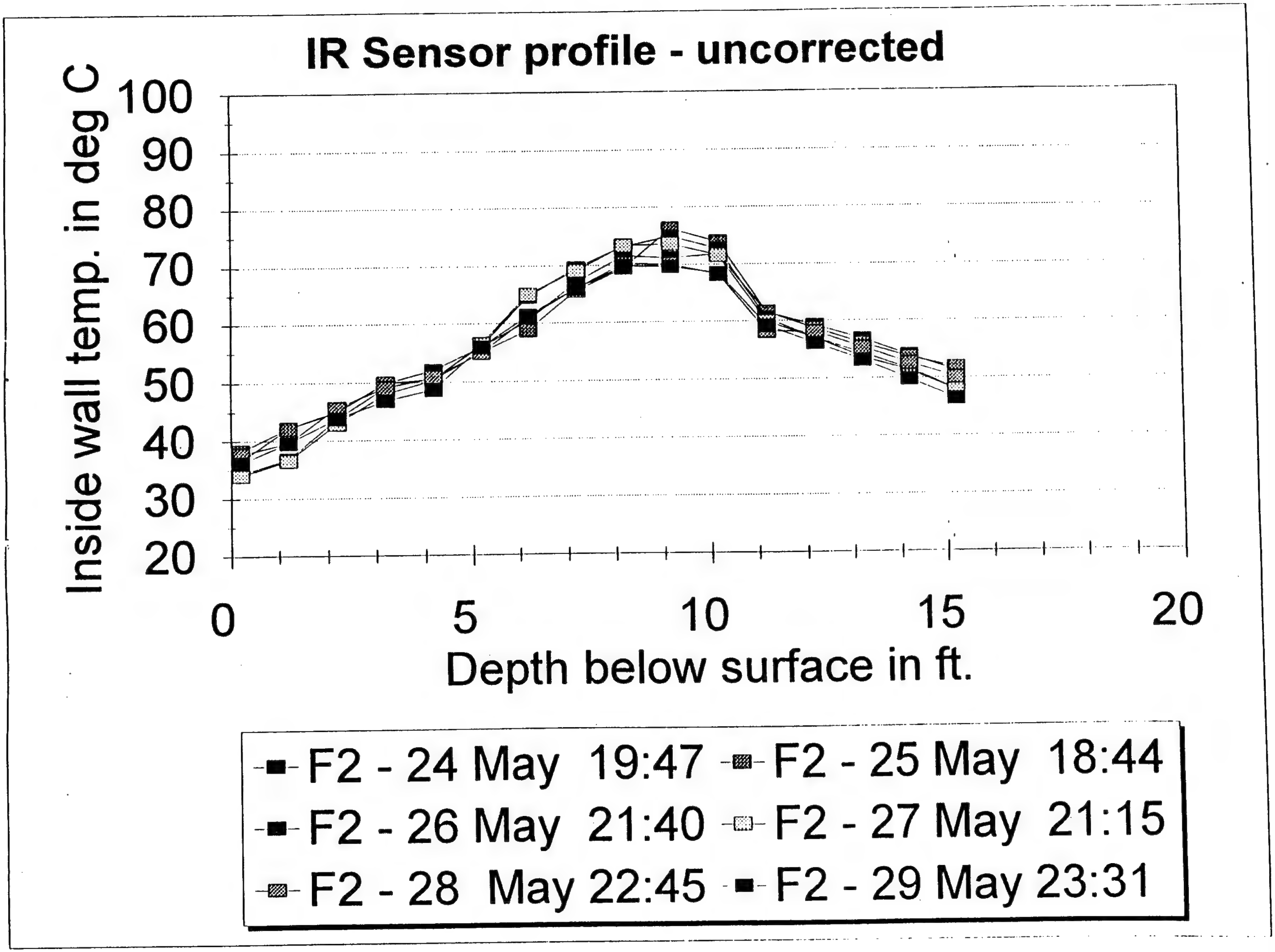


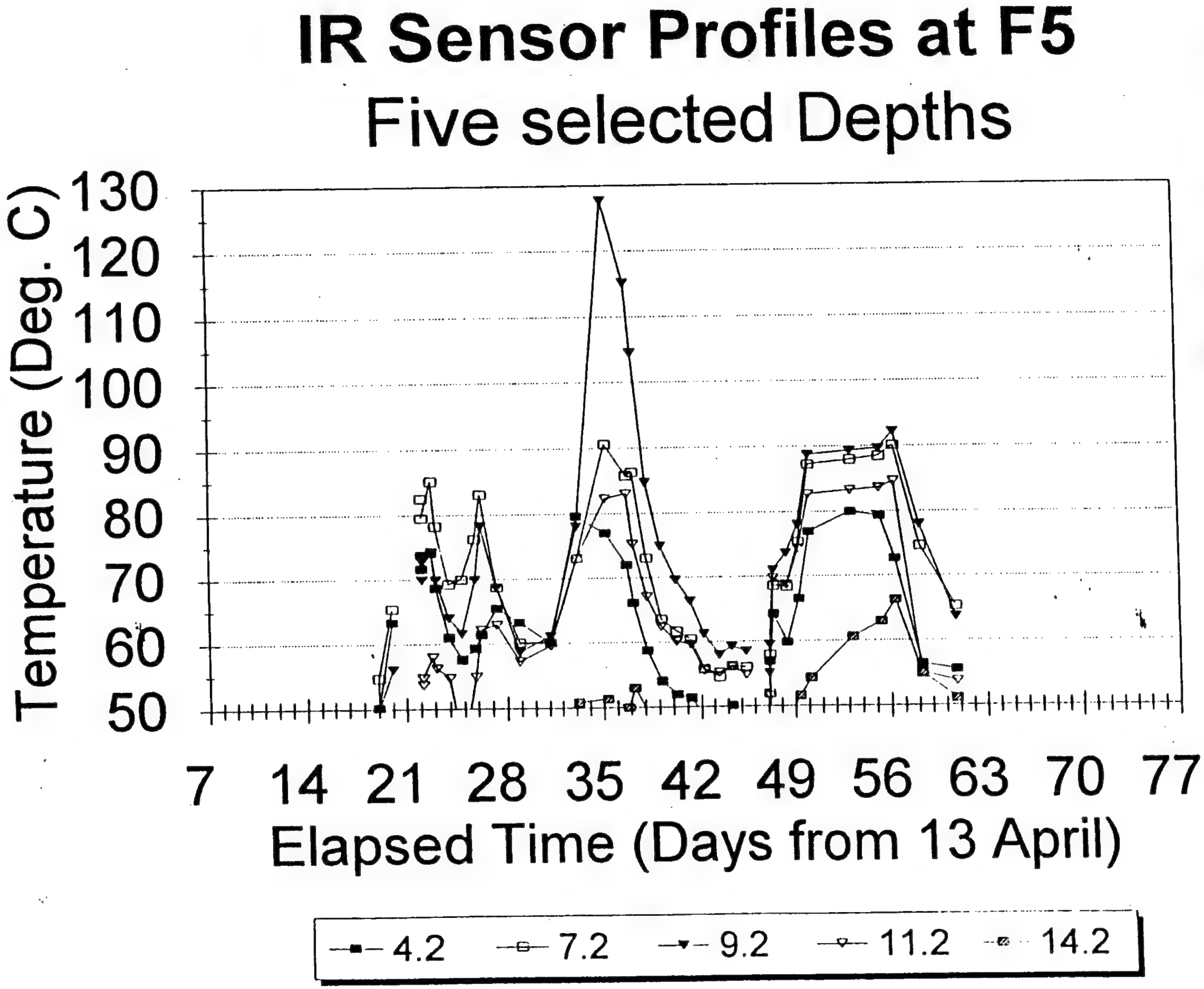
IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F5 - 24 May 19:47
F5 - 25 May 18:44
F5 - 26 May 21:40
F5 - 27 May 21:15
F5 - 28 May 22:45
F5 - 29 May 23:31


IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F2 - 05 Jun 20:10
F2 - 07 Jun 22:14
F2 - 08 Jun 23:35
F2 - 10 Jun 19:10
F2 - 13 Jun 07:35
F2 - 24 Jun 08:33

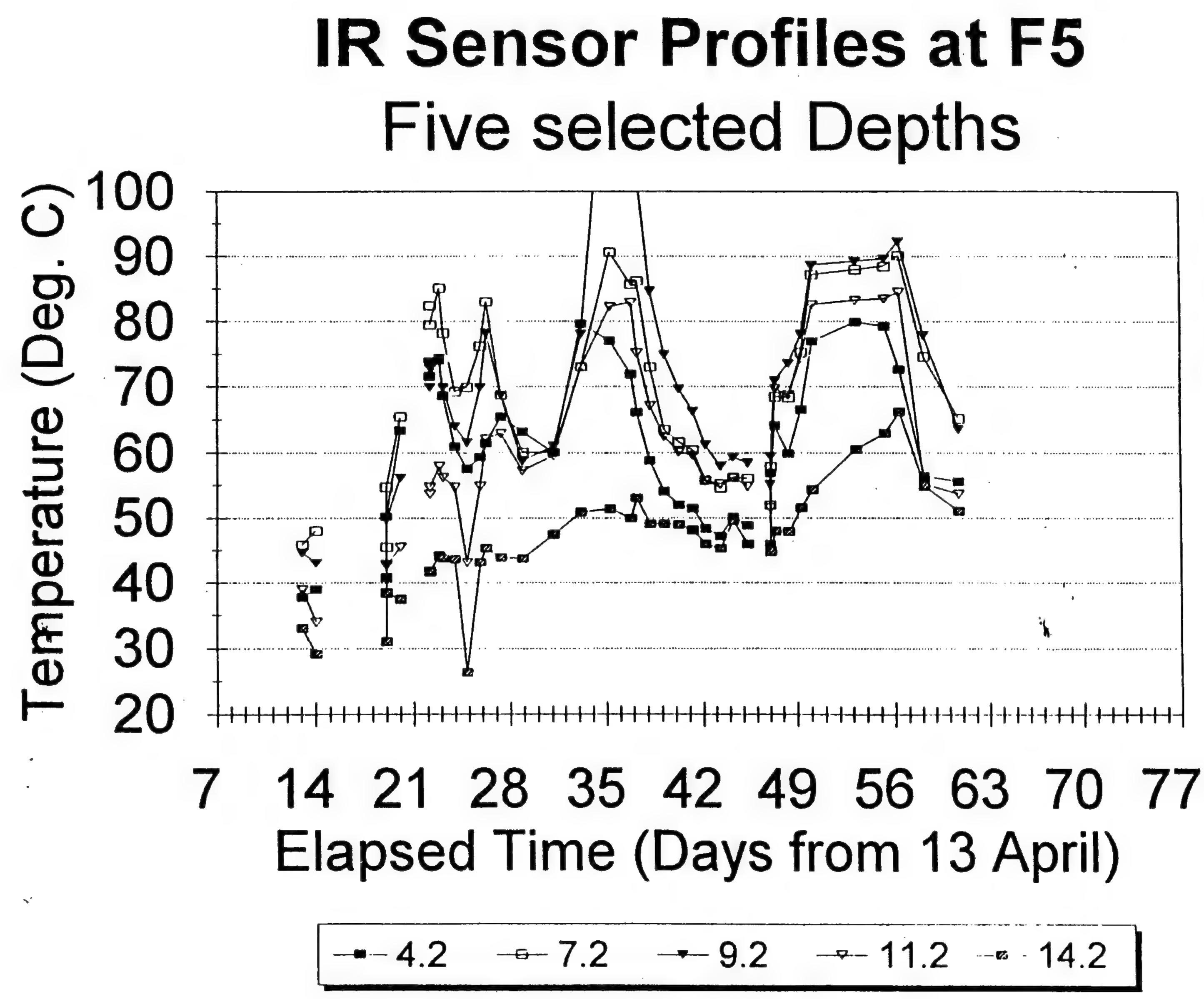

IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F2 - 02 Jun 17:25
F2 - 05 Jun 20:10
F2 - 07 Jun 22:14
F2 - 08 Jun 23:35
F2 - 10 Jun 19:10
F2 - 13 Jun 07:35


IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F2 - 29 May 23:31
F2 - 30 May 16:37
F2 - 30 May 23:33
F2 - 31 May 23:50
F2 - 01 Jun 21:46
F2 - 02 Jun 17:25


IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F2 - 24 May 19:47
F2 - 25 May 18:44
F2 - 26 May 21:40
F2 - 27 May 21:15
F2 - 28 May 22:45
F2 - 29 May 23:31

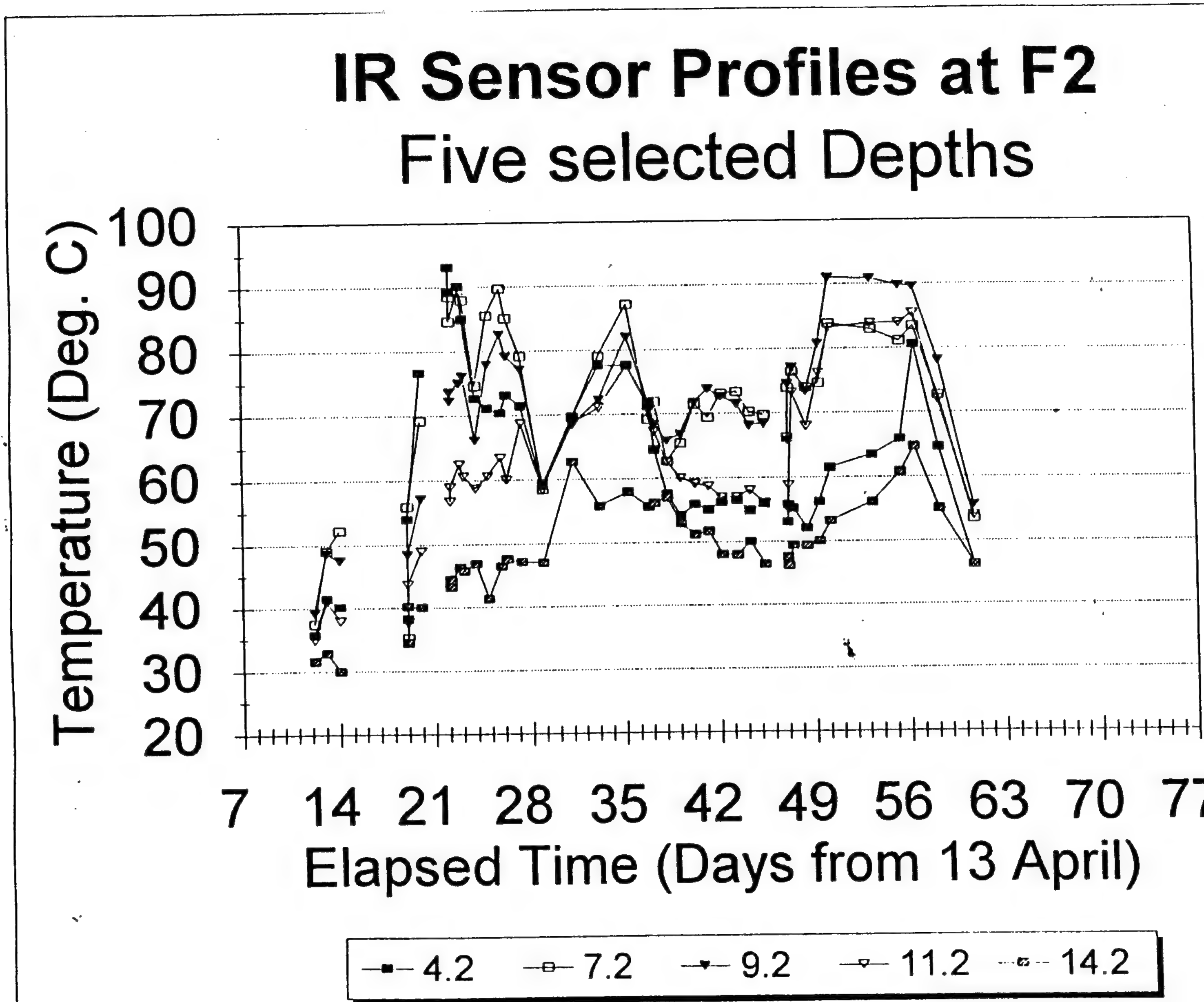

IR Sensor Profiles at F5
Five selected Depths
Temperature (Deg. C)
130
120
110
100
90
80
70
60
50
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
4.2
7.2
9.2
11.2
14.2

DRAFT COPY

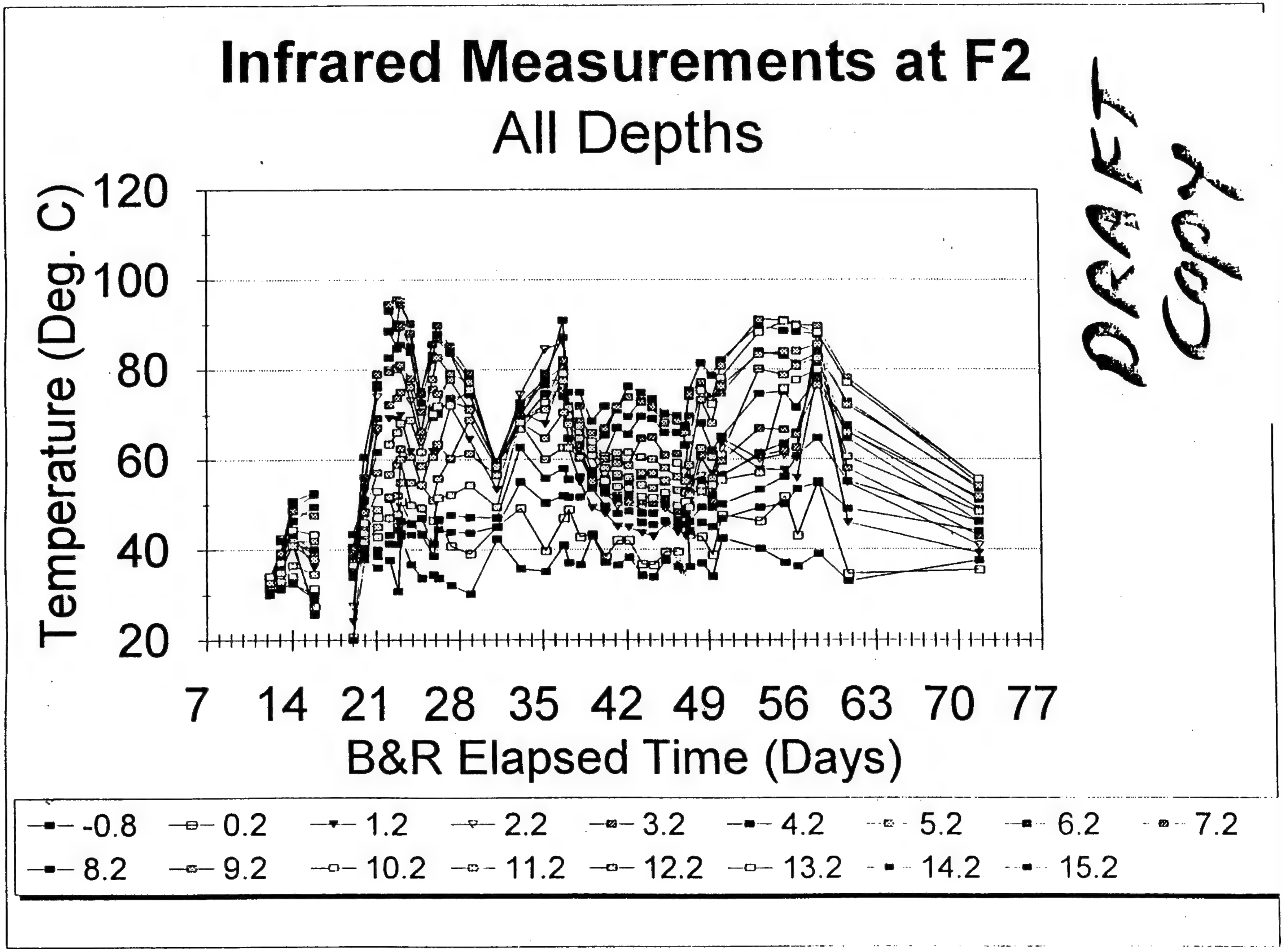


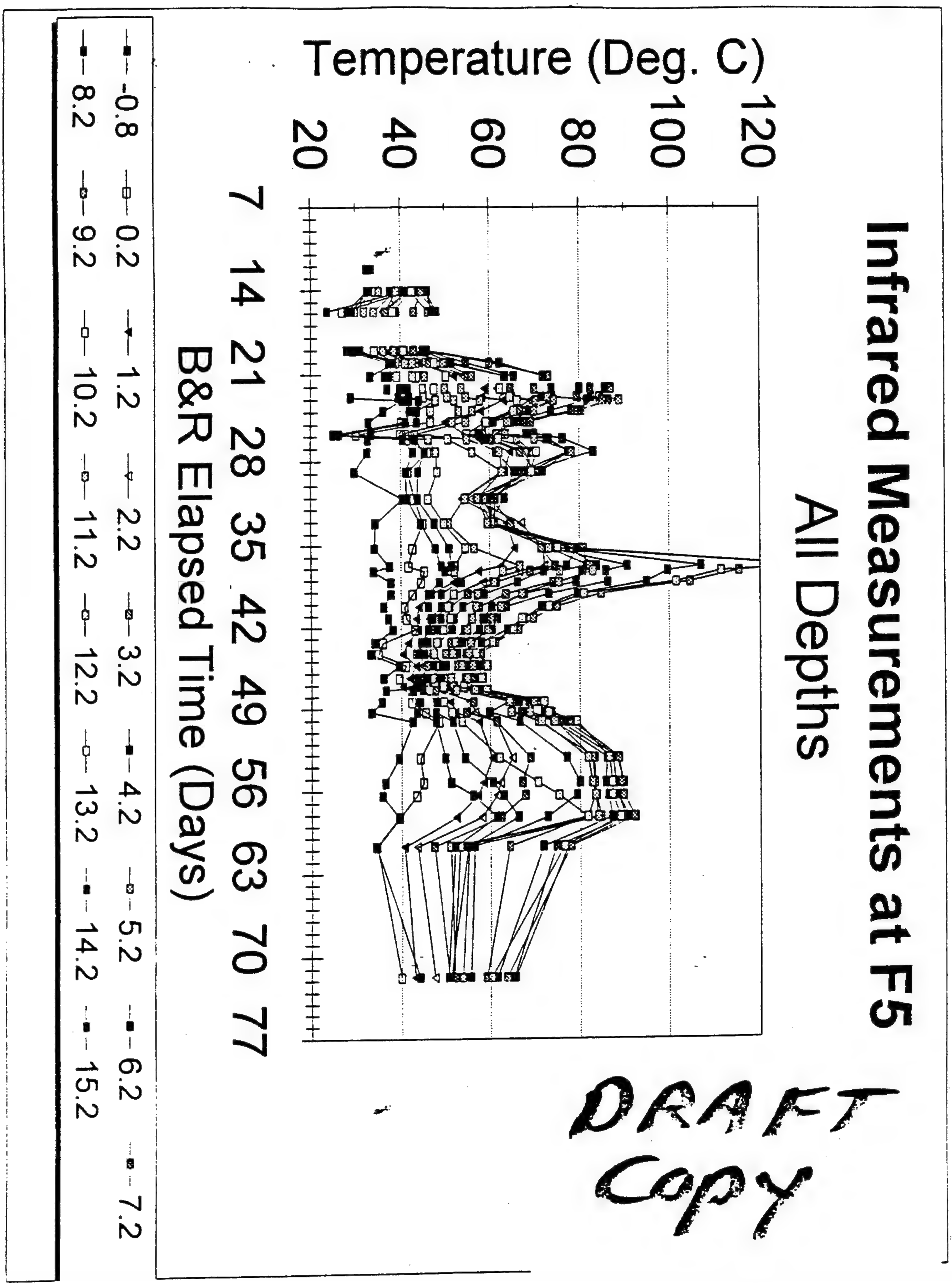
IR Sensor Profiles at F5
Five selected Depths
Temperature (Deg. C)
100
90
80
70
60
50
40
30
20
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
4.2
7.2
9.2
11.2
14.2

DRAFT Copy


IR Sensor Profiles at F2
Five selected Depths
Temperature (Deg. C)
100
90
80
70
60
50
40
30
20
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
4.2
7.2
9.2
11.2
14.2

DRAFT Copy


Infrared Measurements at F2
All Depths
Temperature (Deg. C)
20
40
60
80
100
120
7 14 21 28 35 42 49 56 63 70 77
B&R Elapsed Time (Days)
-0.8 0.2 1.2 2.2 3.2 4.2 5.2 6.2 7.2
8.2 9.2 10.2 11.2 12.2 13.2 14.2 15.2
DRAFT
Copy


Infrared Measurements at F5
All Depths
Temperature (Deg. C)
120
100
80
60
40
20
7 14 21 28 35 42 49 56 63 70 77
B&R Elapsed Time (Days)
-0.8
0.2
1.2
2.2
3.2
4.2
5.2
6.2
7.2
8.2
9.2
10.2
11.2
12.2
13.2
14.2
15.2
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APPENDIX F - Temperature Profiles Using An IR Probe
Infrared probe measurements

NOTE: All IR temperature plots are labeled "UNCORRECTED" to alert the reviewer to both the fact that the probe is not a liner, absolute calibration device and because these measurements must be considered within the context of air flow around the wall of the borehole being measured.

- Measurement plots of F2 and F5 were clustered about heating borehole liner A2. This liner, A2 was the first heating location. The borehole was loaded with Applicator #1 on heating channel #1.

  Plot F2 over a 7 to 77 day span - All depths
  Plot F5 over a 7 to 77 day span - All depths

  Plot F2 over a 7 to 77 day span at 5 depths
  Plot F5 over a 7 to 77 day span at 5 depths (100 deg C scale)
  Plot F5 over a 7 to 77 day span at 5 depths (130 deg C scale)

  F2 Temperature profiles - 24 May to 29 May
  F2 Temperature profiles - 29 May to 02 June
  F2 Temperature profiles - 02 June to 13 June
  F2 Temperature profiles - 05 June to 24 June

  F5 Temperature profiles - 24 May to 29 May
  F5 Temperature profiles - 29 May to 02 June
  F5 Temperature profiles - 02 June to 13 June
  F5 Temperature profiles - 05 June to 24 June

- Measurement plots of F1 and F4 were clustered about heating borehole liner A1. This liner, A1 was the second heating location. The borehole was loaded with Applicator #2 on heating channel #2.

  Plot F1 over a 7 to 77 day span - All depths
  Plot F4 over a 7 to 77 day span - All depths

  Plot F1 over a 7 to 77 day span at 5 depths
  Plot F4 over a 7 to 77 day span at 5 depths

  F1 Temperature profiles - 24 May to 29 May
  F1 Temperature profiles - 29 May to 02 June
  F1 Temperature profiles - 02 June to 13 June
  F1 Temperature profiles - 05 June to 24 June

  F4 Temperature profiles - 24 May to 29 May
  F4 Temperature profiles - 29 May to 02 June
  F4 Temperature profiles - 02 June to 13 June
  F4 Temperature profiles - 05 June to 24 June

- Measurement plots of F3 were associated with the heating from liner locations A2 and A1.

  Plot F3 over a 7 to 77 day span - All depths
  Plot F3 over a 7 to 77 day span - at 5 depths

  F3 Temperature profiles - 24 May to 29 May

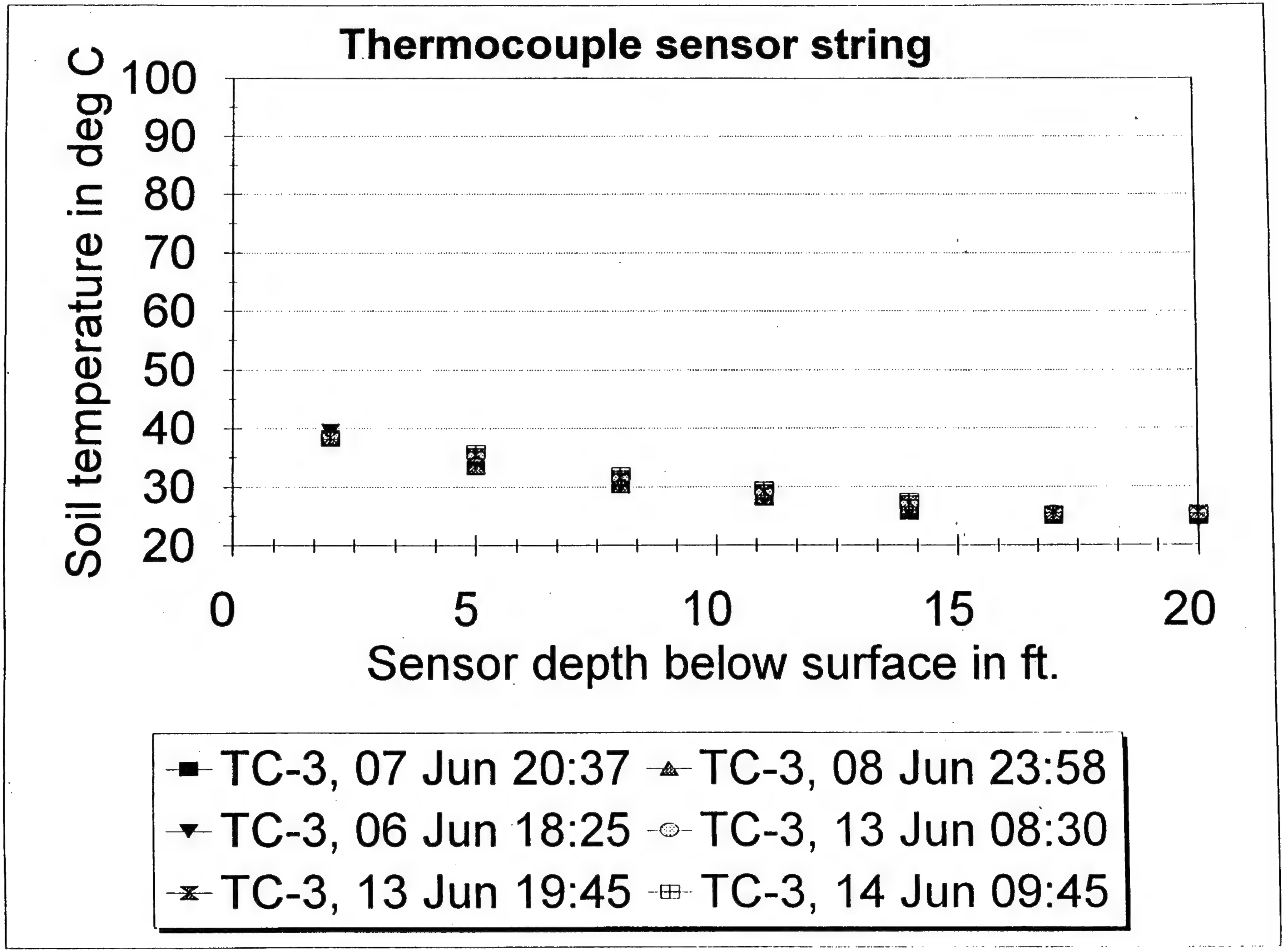
F3 Temperature profiles - 29 May to 02 June
F3 Temperature profiles - 02 June to 13 June
F3 Temperature profiles - 05 June to 24 June

- Applicator well liner temperature profiles (Applicators are removed from well for periods of 15 minutes to several weeks after the RF energy is turned off). See Appendix B to determine delay from heating time for individual plots.

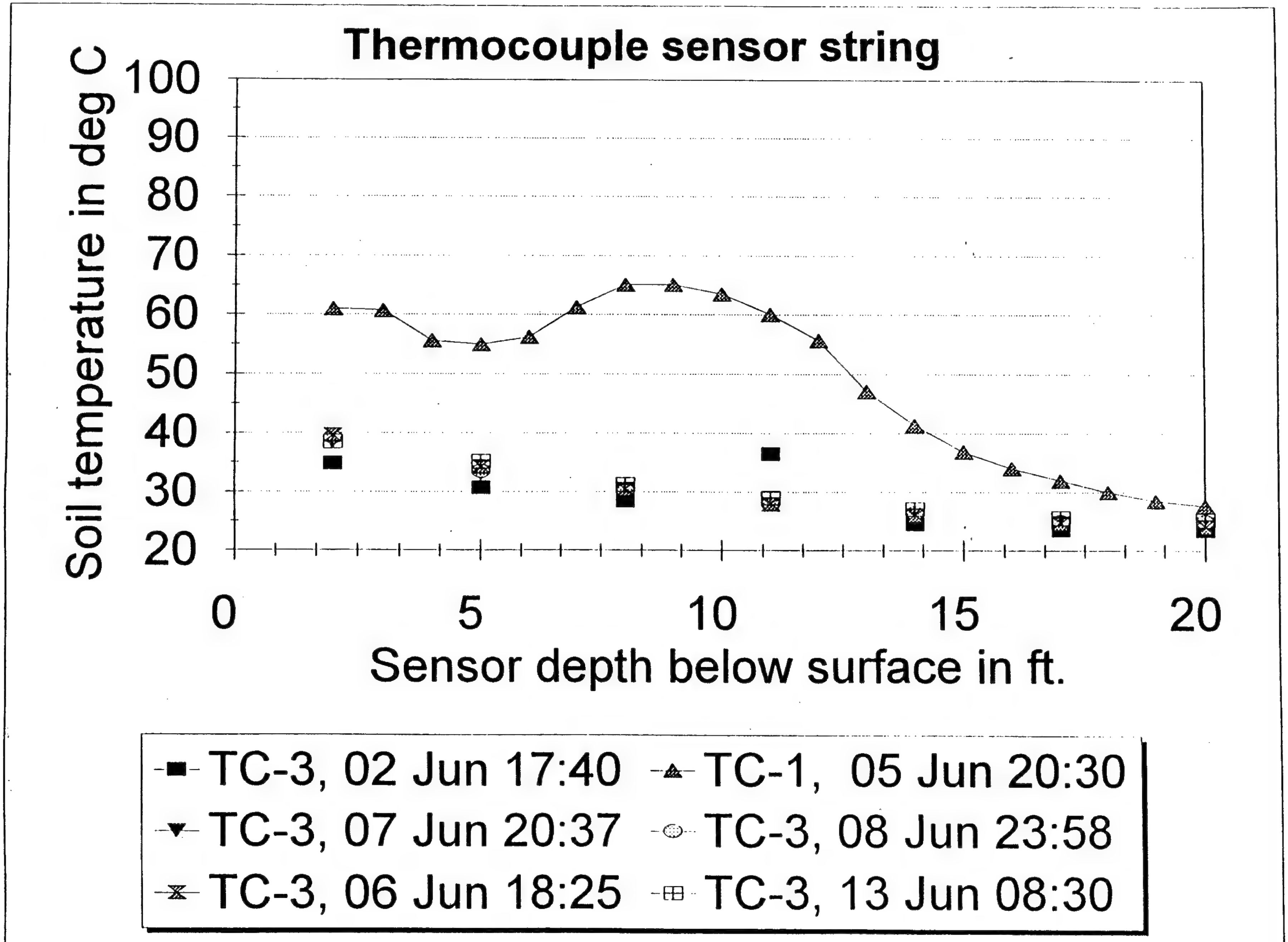
A2 Temperature profiles - 19 April to 10 June (Applicator #1)
A2 Temperature profiles - 23 April to 24 June (Applicator #1)

A1 Temperature profiles - 15 April to 24 June (Applicator #2)

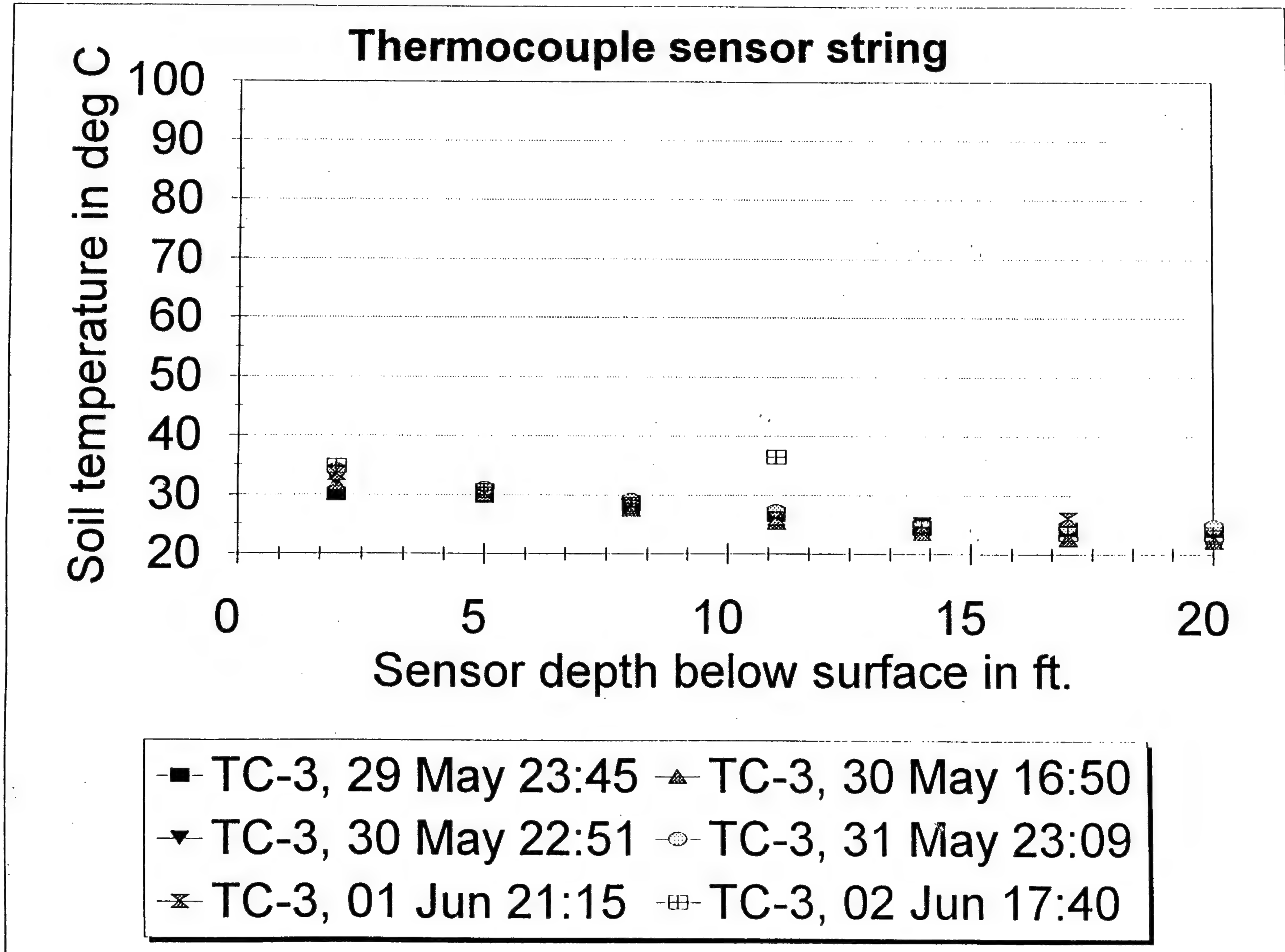
END FILE: KELLYF.A



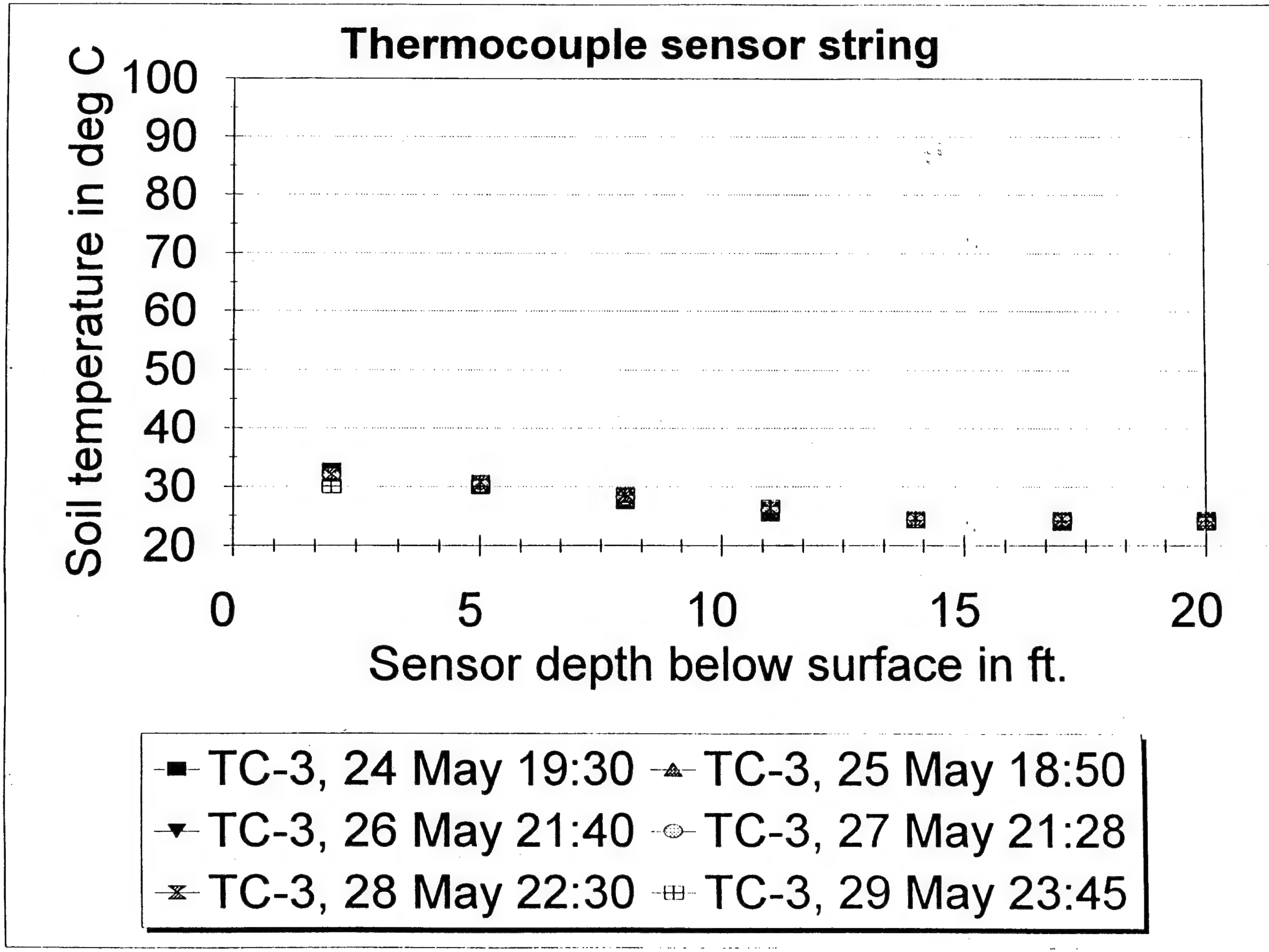
Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-3, 07 Jun 20:37
TC-3, 08 Jun 23:58
TC-3, 06 Jun 18:25
TC-3, 13 Jun 08:30
TC-3, 13 Jun 19:45
TC-3, 14 Jun 09:45

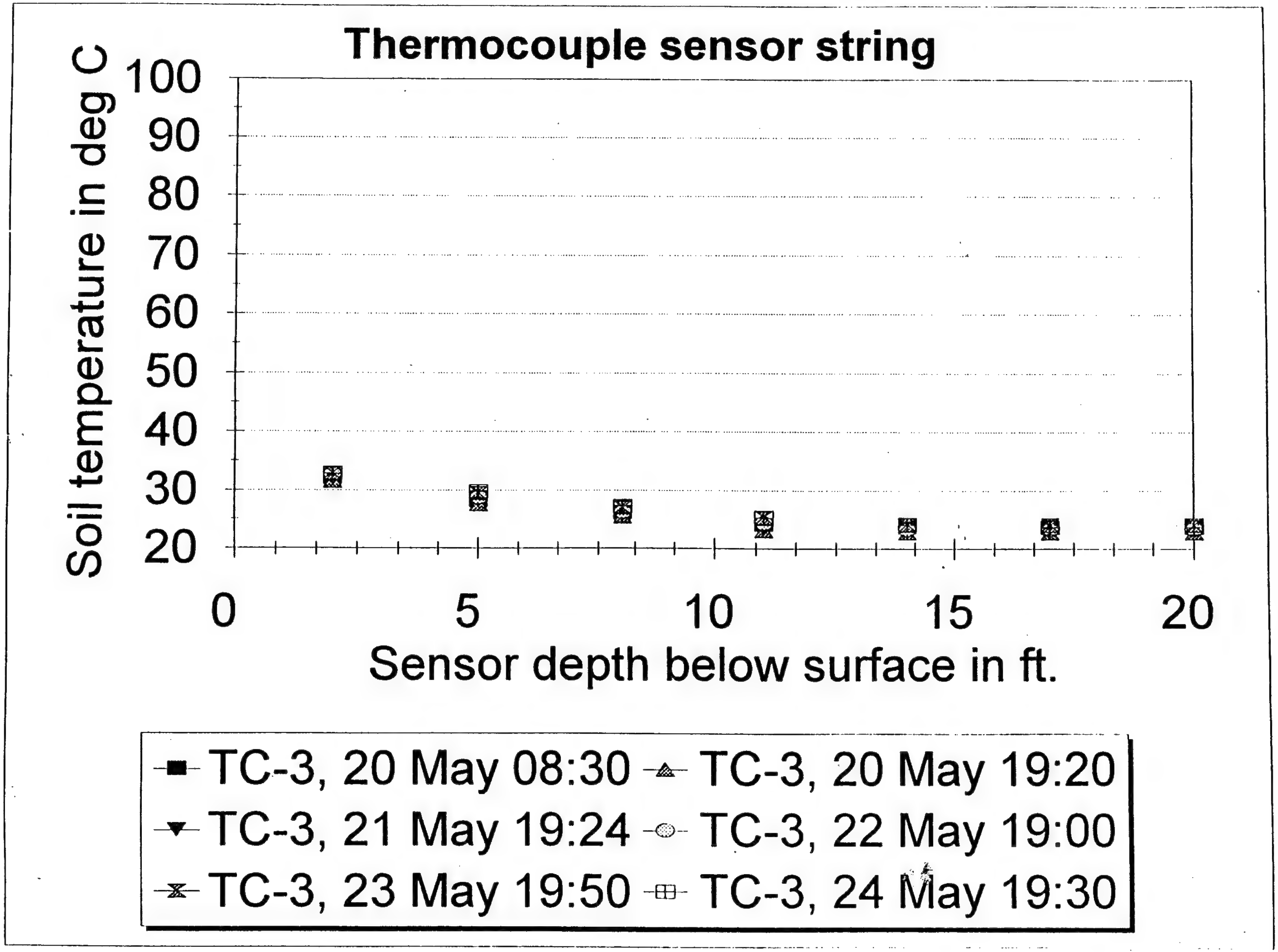


Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-3, 02 Jun 17:40
TC-1, 05 Jun 20:30
TC-3, 07 Jun 20:37
TC-3, 08 Jun 23:58
TC-3, 06 Jun 18:25
TC-3, 13 Jun 08:30

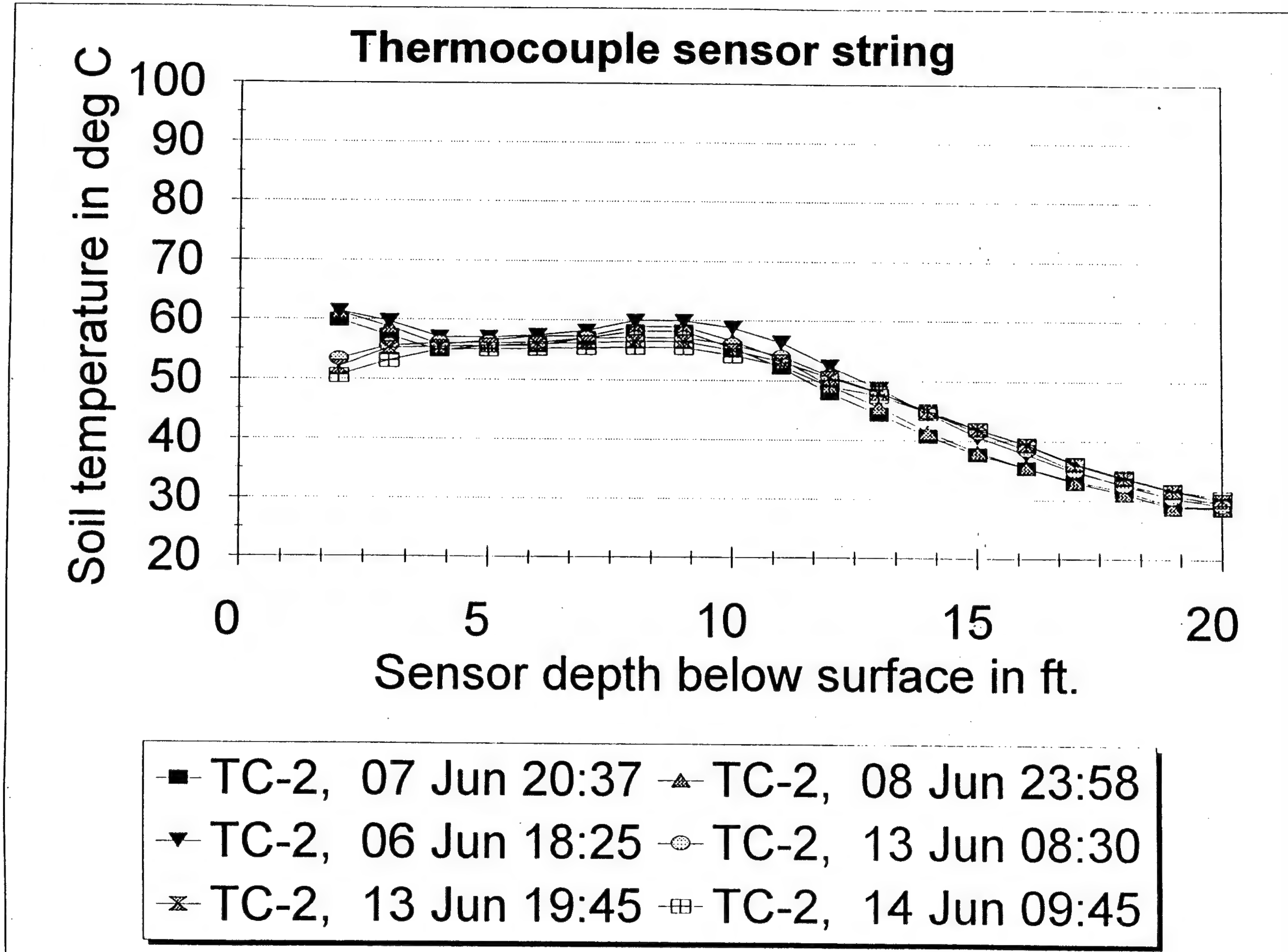


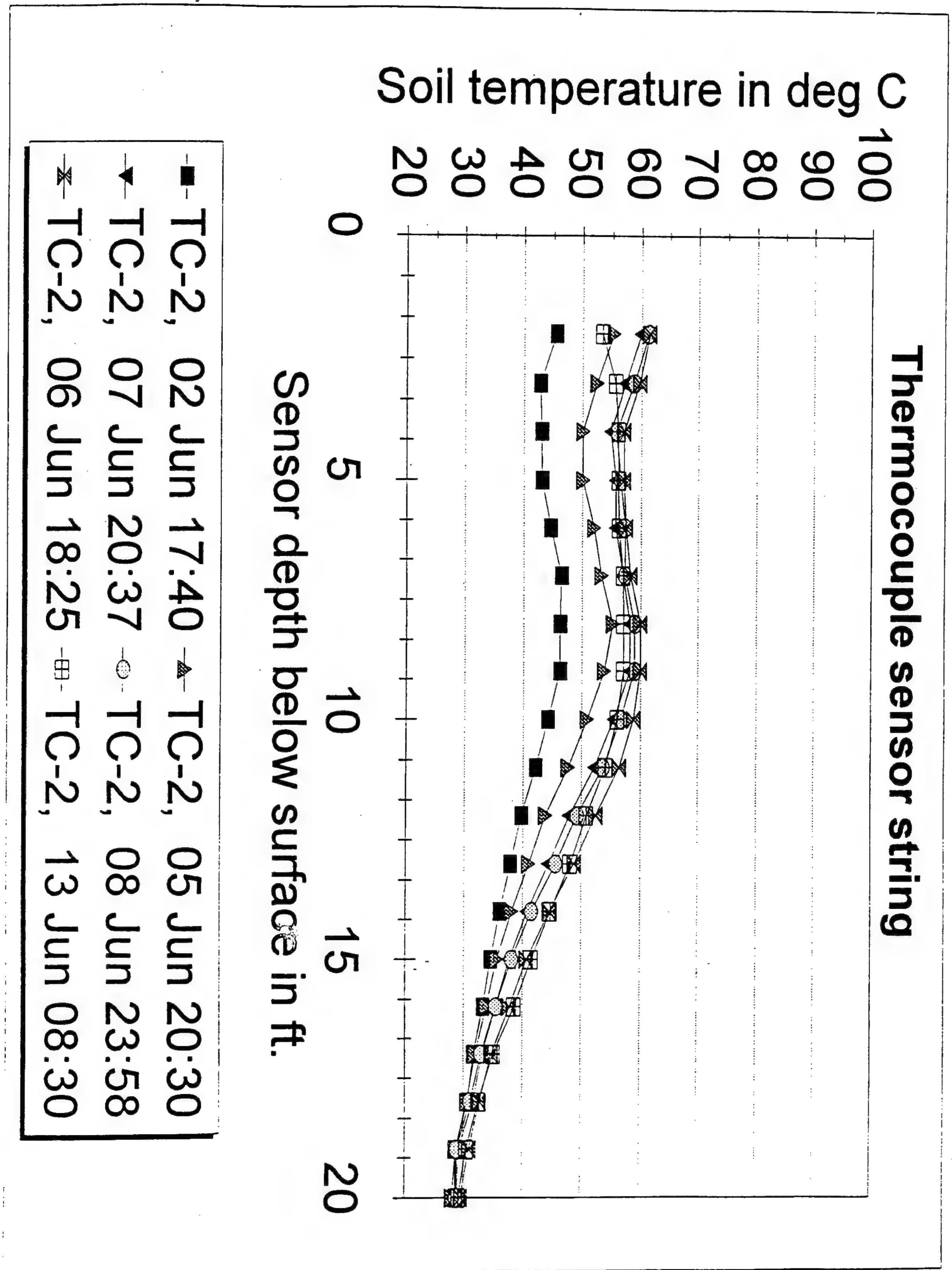
Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-3, 29 May 23:45
TC-3, 30 May 16:50
TC-3, 30 May 22:51
TC-3, 31 May 23:09
TC-3, 01 Jun 21:15
TC-3, 02 Jun 17:40


Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-3, 24 May 19:30
TC-3, 25 May 18:50
TC-3, 26 May 21:40
TC-3, 27 May 21:28
TC-3, 28 May 22:30
TC-3, 29 May 23:45

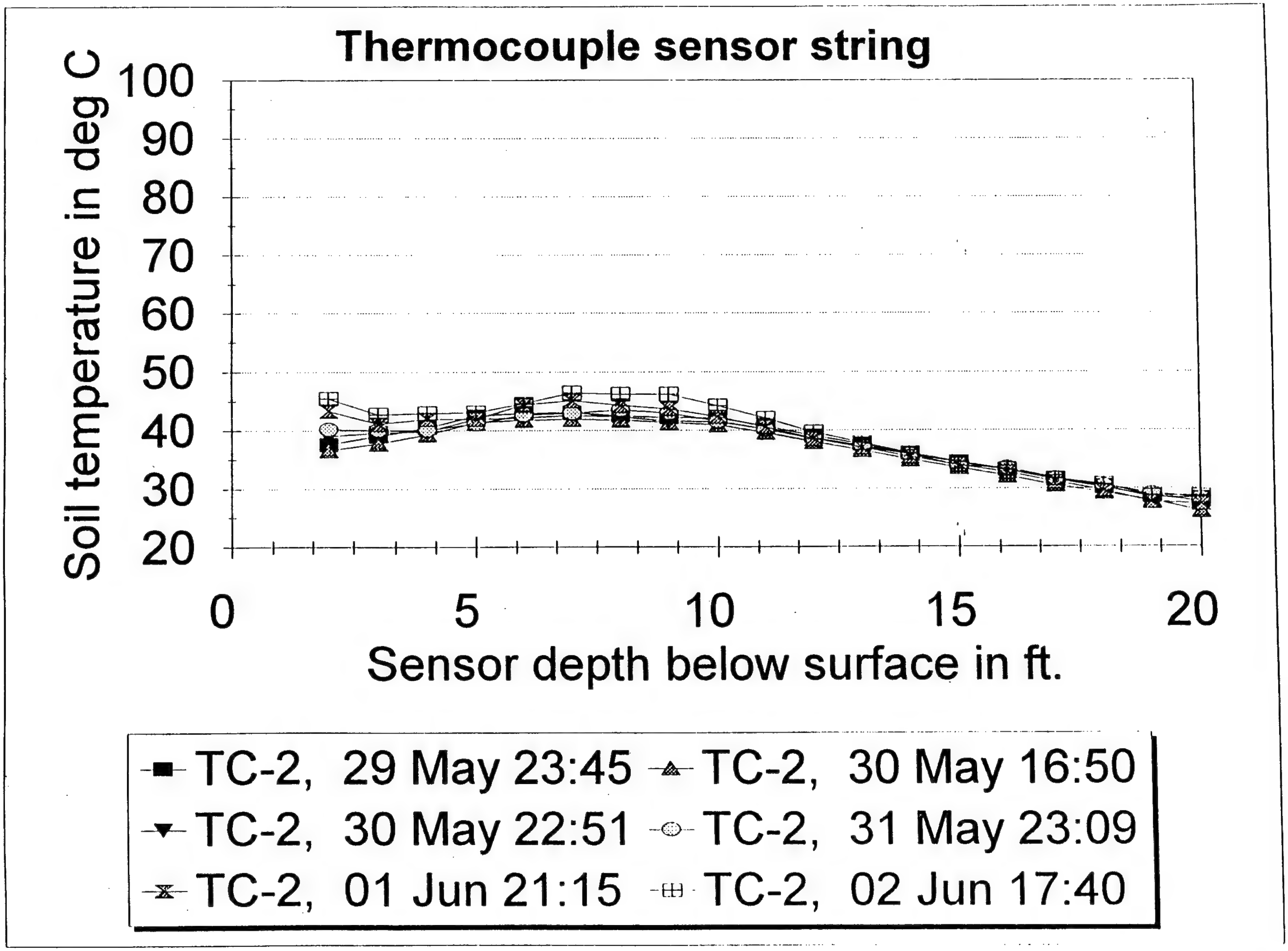


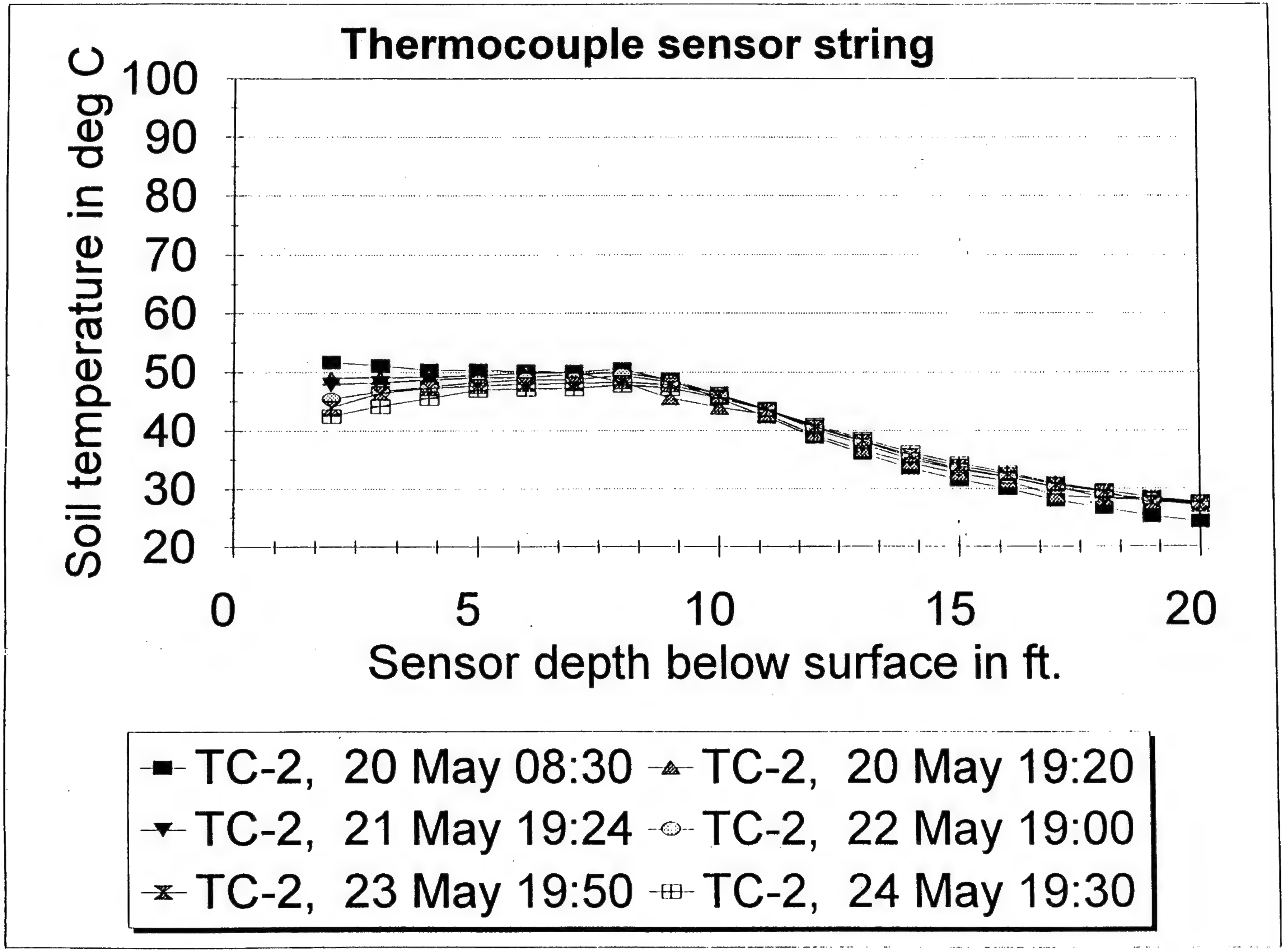
Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-3, 20 May 08:30
TC-3, 20 May 19:20
TC-3, 21 May 19:24
TC-3, 22 May 19:00
TC-3, 23 May 19:50
TC-3, 24 May 19:30

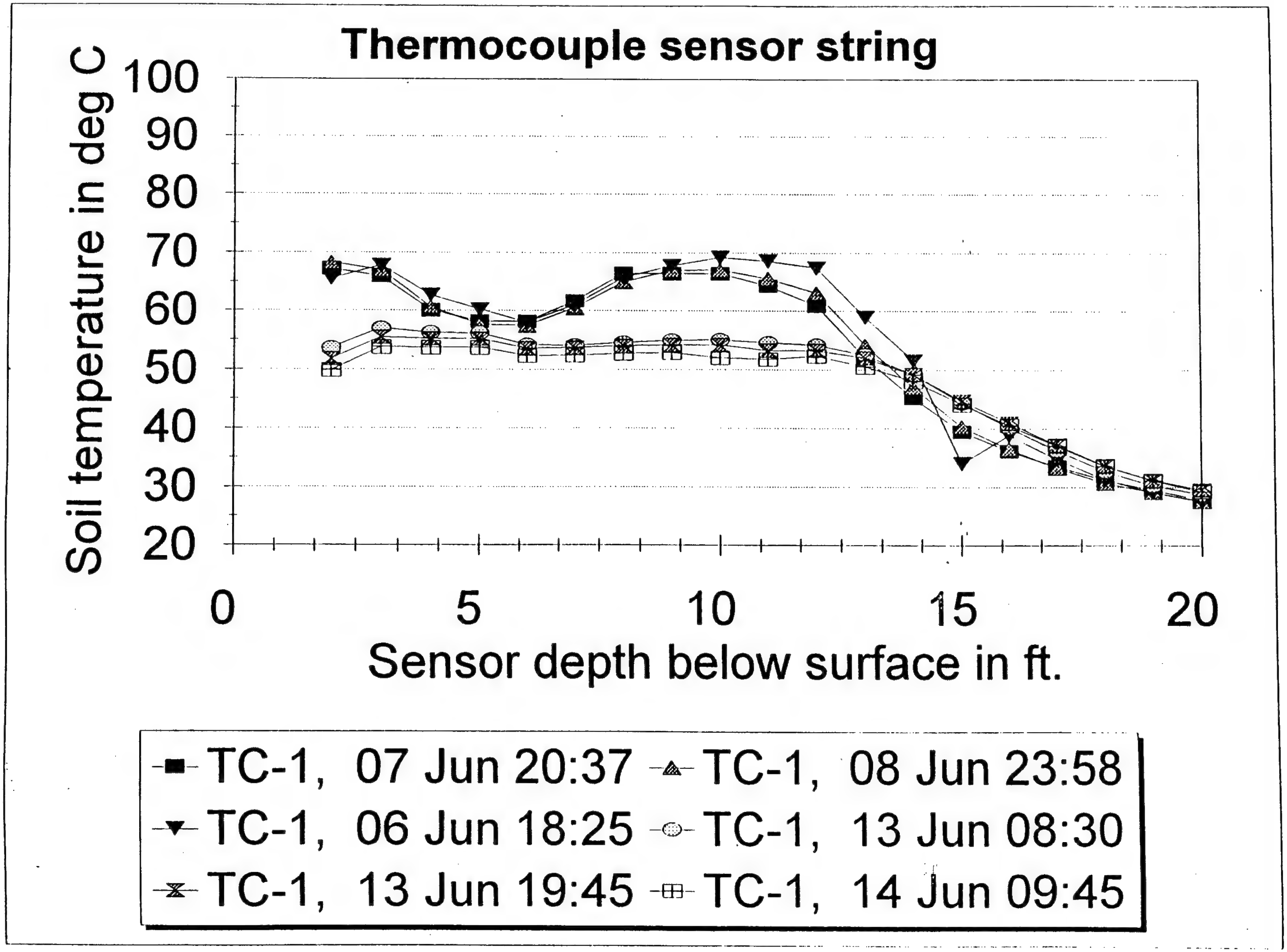

Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-2, 07 Jun 20:37
TC-2, 08 Jun 23:58
TC-2, 06 Jun 18:25
TC-2, 13 Jun 08:30
TC-2, 13 Jun 19:45
TC-2, 14 Jun 09:45

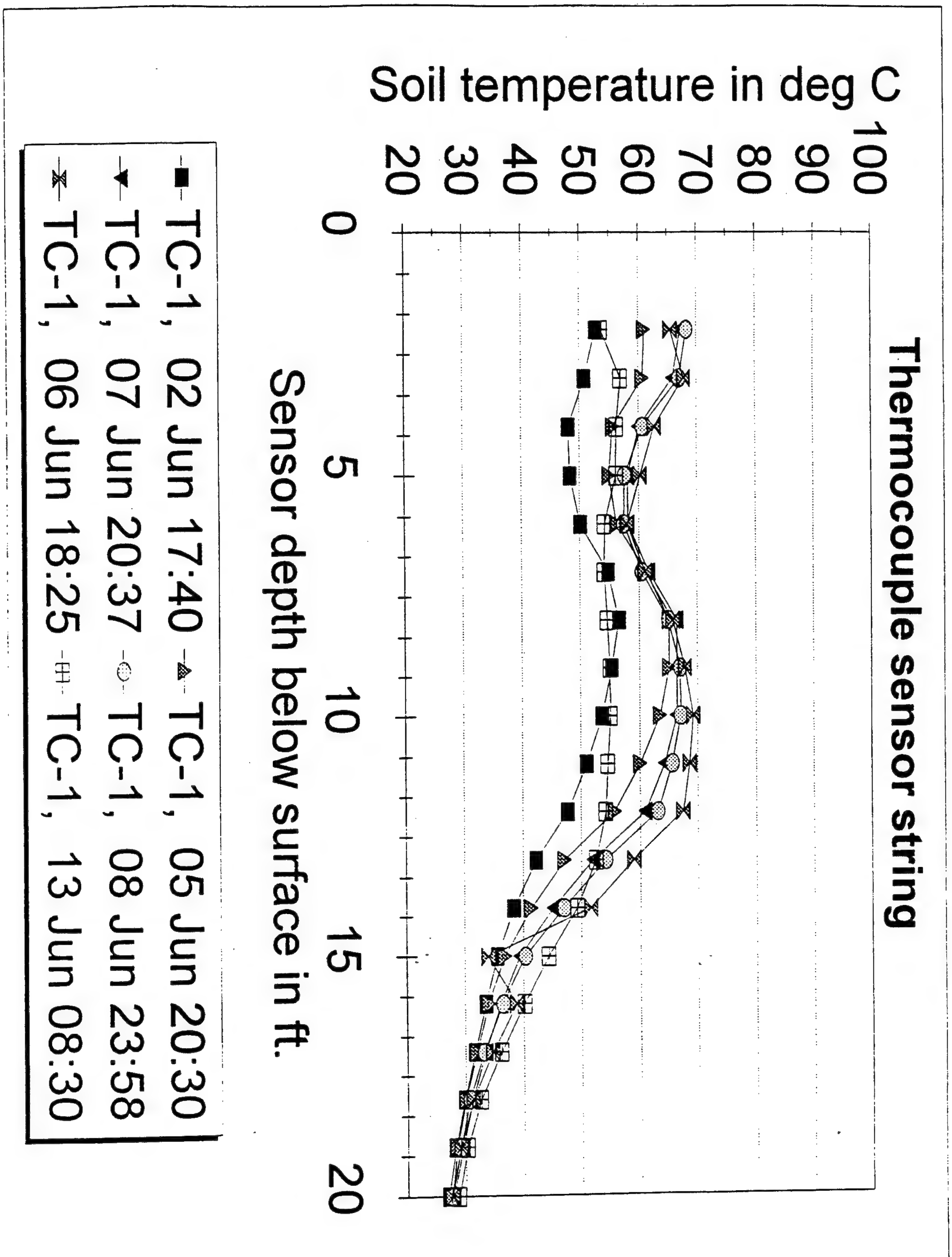


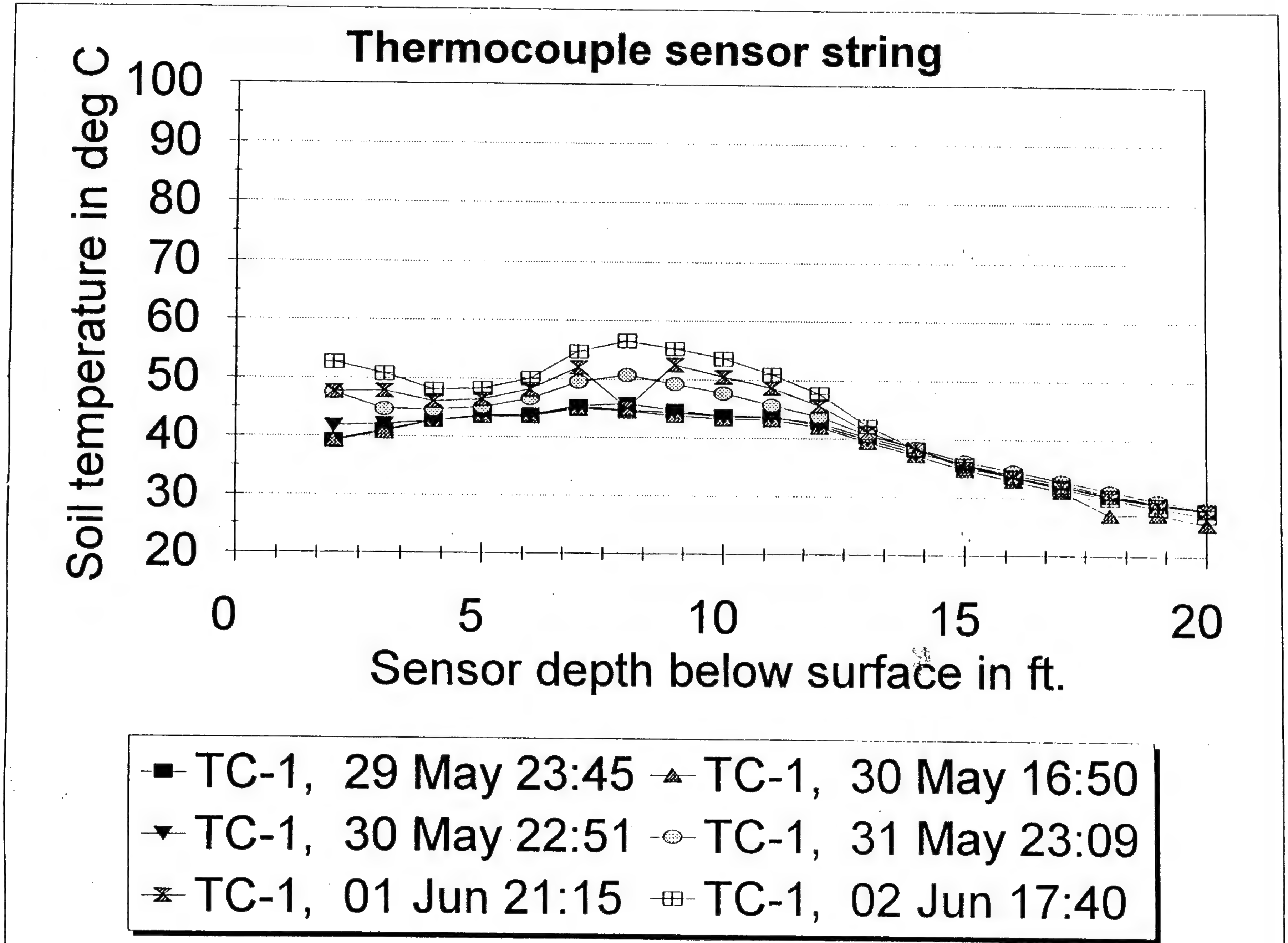
Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-2, 02 Jun 17:40
TC-2, 05 Jun 20:30
TC-2, 07 Jun 20:37
TC-2, 08 Jun 23:58
TC-2, 06 Jun 18:25
TC-2, 13 Jun 08:30

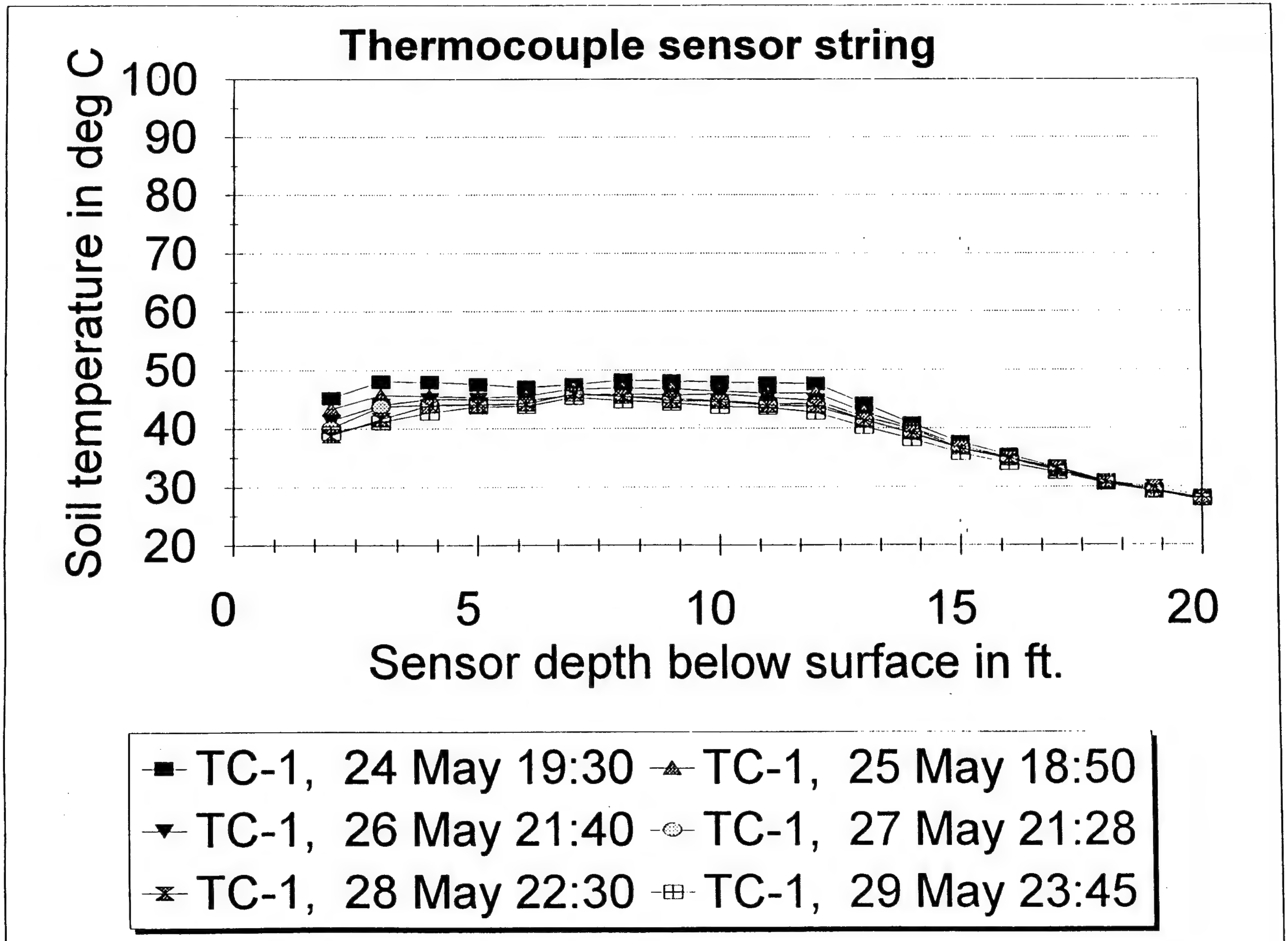

Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-2, 29 May 23:45
TC-2, 30 May 16:50
TC-2, 30 May 22:51
TC-2, 31 May 23:09
TC-2, 01 Jun 21:15
TC-2, 02 Jun 17:40

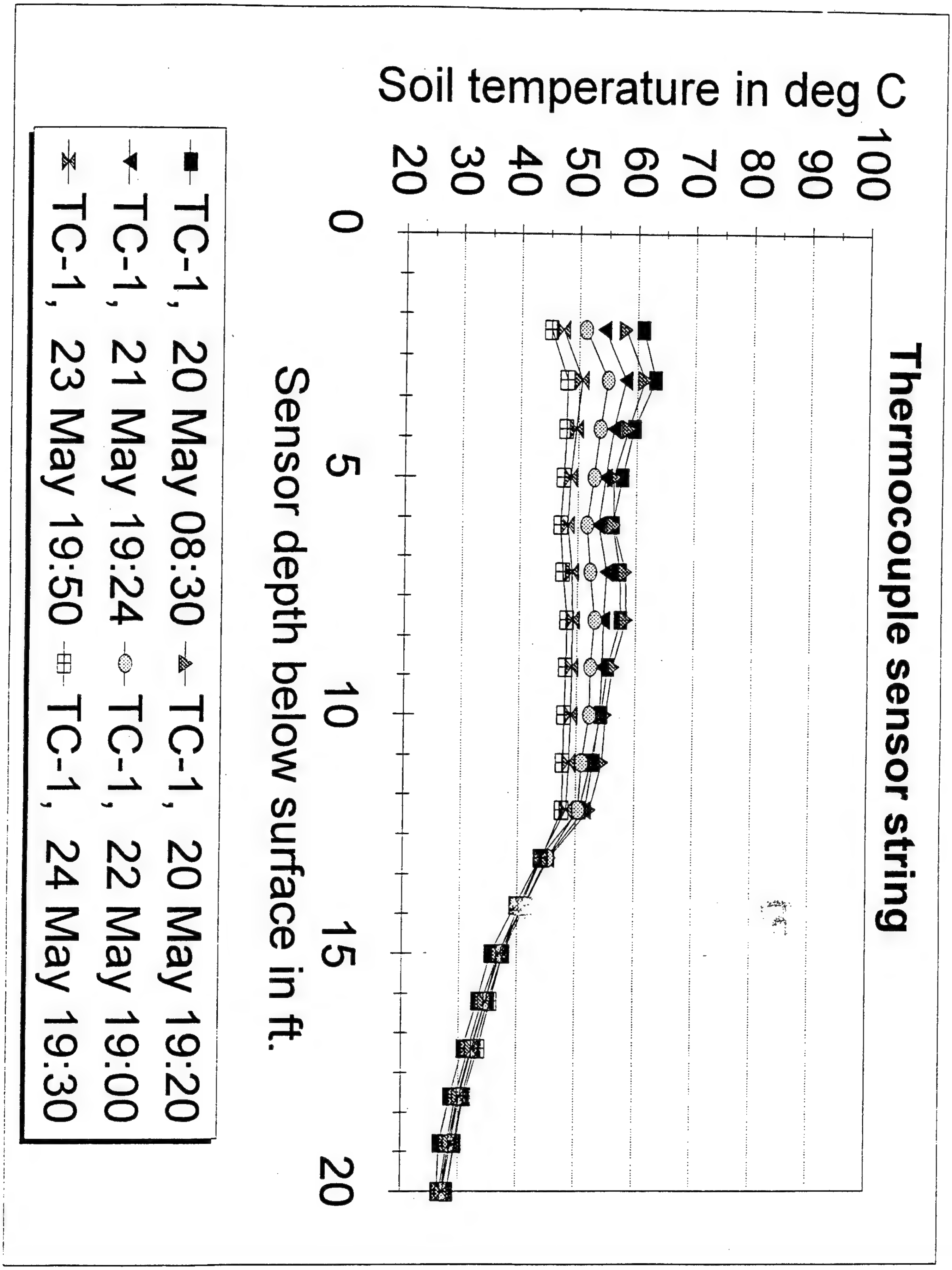

Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-2, 20 May 08:30
TC-2, 20 May 19:20
TC-2, 21 May 19:24
TC-2, 22 May 19:00
TC-2, 23 May 19:50
TC-2, 24 May 19:30

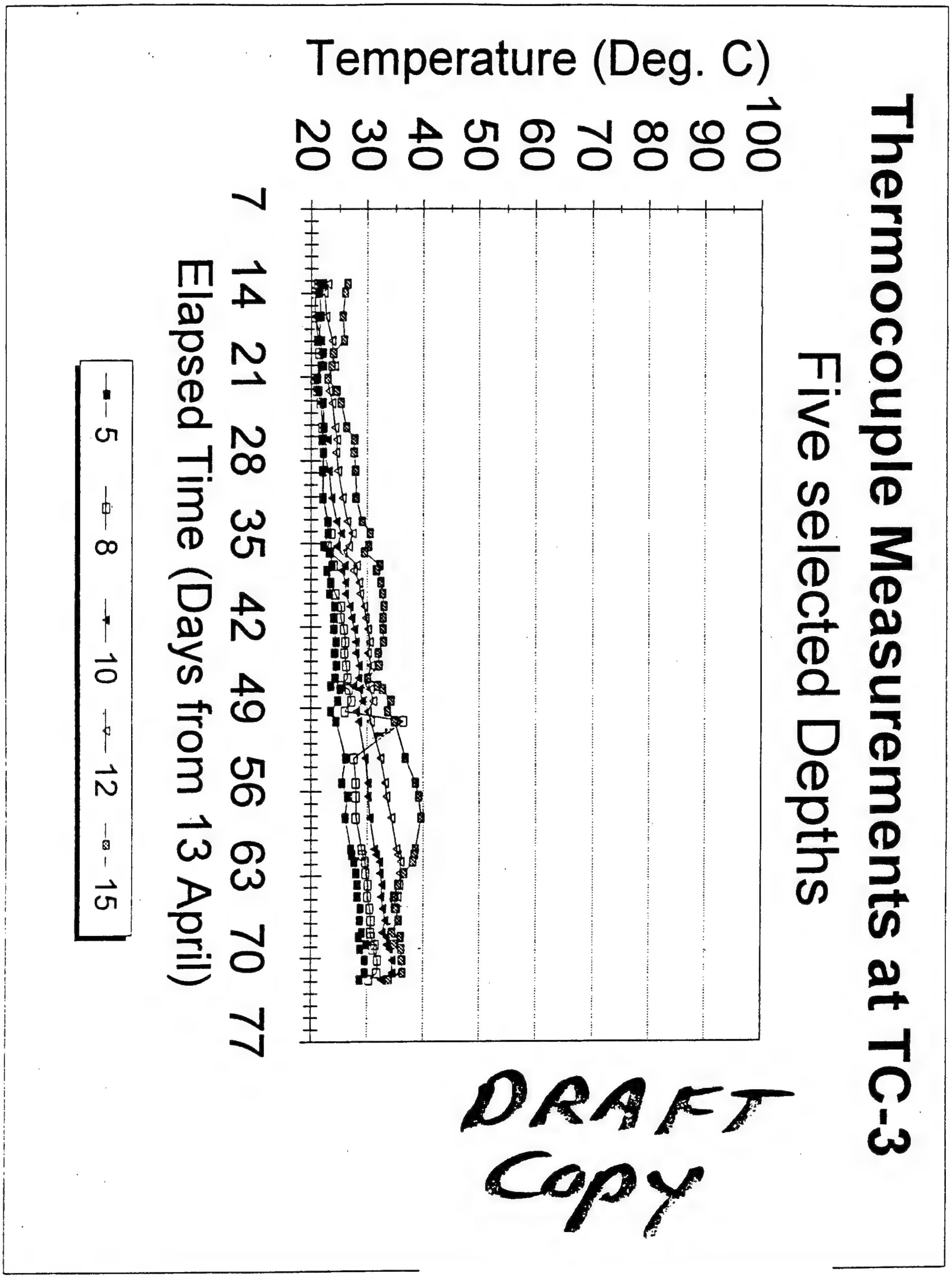

Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-1, 07 Jun 20:37
TC-1, 08 Jun 23:58
TC-1, 06 Jun 18:25
TC-1, 13 Jun 08:30
TC-1, 13 Jun 19:45
TC-1, 14 Jun 09:45


Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-1, 02 Jun 17:40
TC-1, 05 Jun 20:30
TC-1, 07 Jun 20:37
TC-1, 08 Jun 23:58
TC-1, 06 Jun 18:25
TC-1, 13 Jun 08:30


Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-1, 29 May 23:45
TC-1, 30 May 16:50
TC-1, 30 May 22:51
TC-1, 31 May 23:09
TC-1, 01 Jun 21:15
TC-1, 02 Jun 17:40


Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-1, 24 May 19:30
TC-1, 25 May 18:50
TC-1, 26 May 21:40
TC-1, 27 May 21:28
TC-1, 28 May 22:30
TC-1, 29 May 23:45


Thermocouple sensor string
Soil temperature in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Sensor depth below surface in ft.
TC-1, 20 May 08:30
TC-1, 20 May 19:20
TC-1, 21 May 19:24
TC-1, 22 May 19:00
TC-1, 23 May 19:50
TC-1, 24 May 19:30



Thermocouple Measurements at TC-3
Five selected Depths
Temperature (Deg. C)
20
30
40
50
60
70
80
90
100
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
5
8
10
12
15

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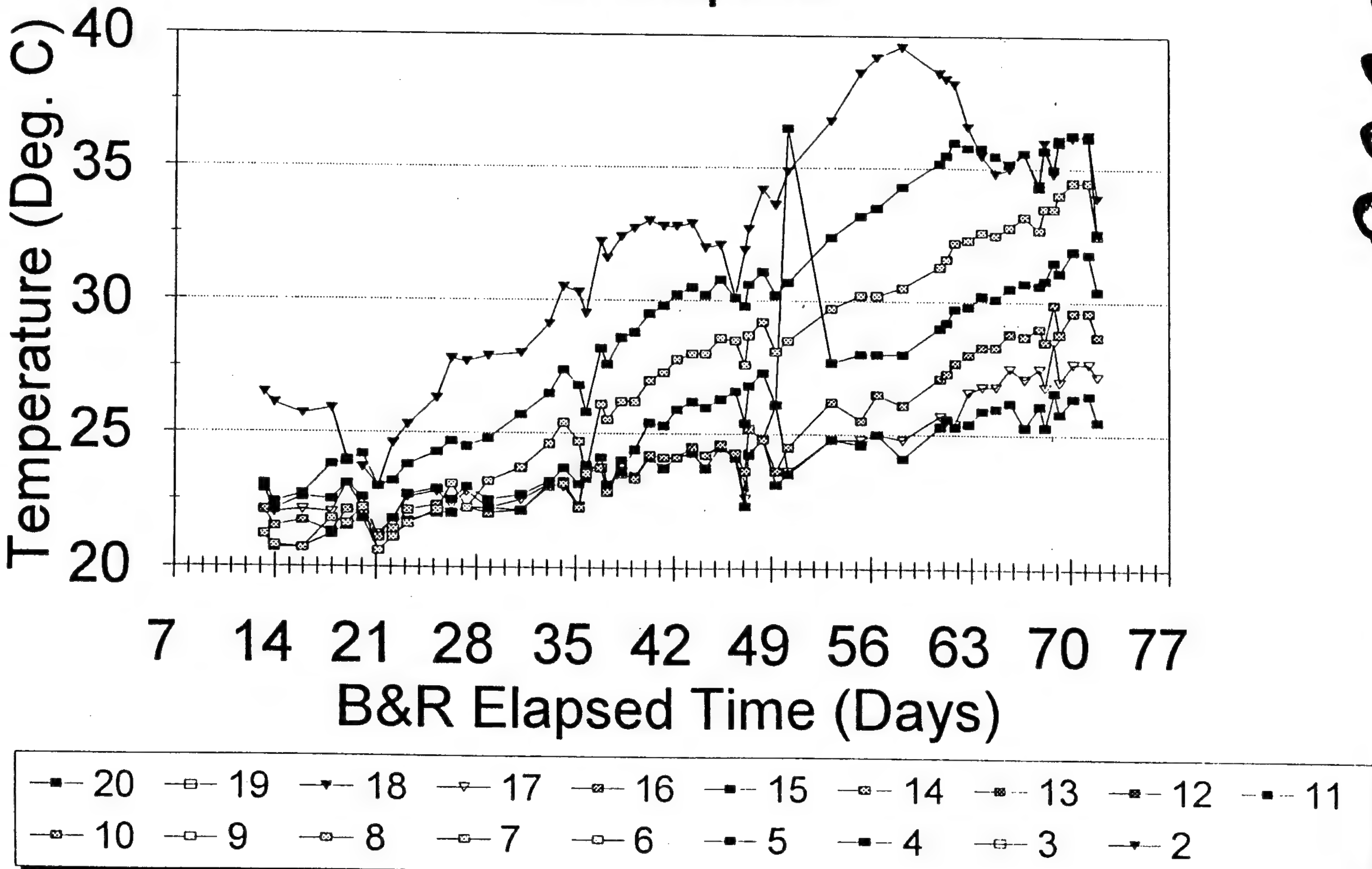
Thermocouple Measurements at TC-3
All Depths



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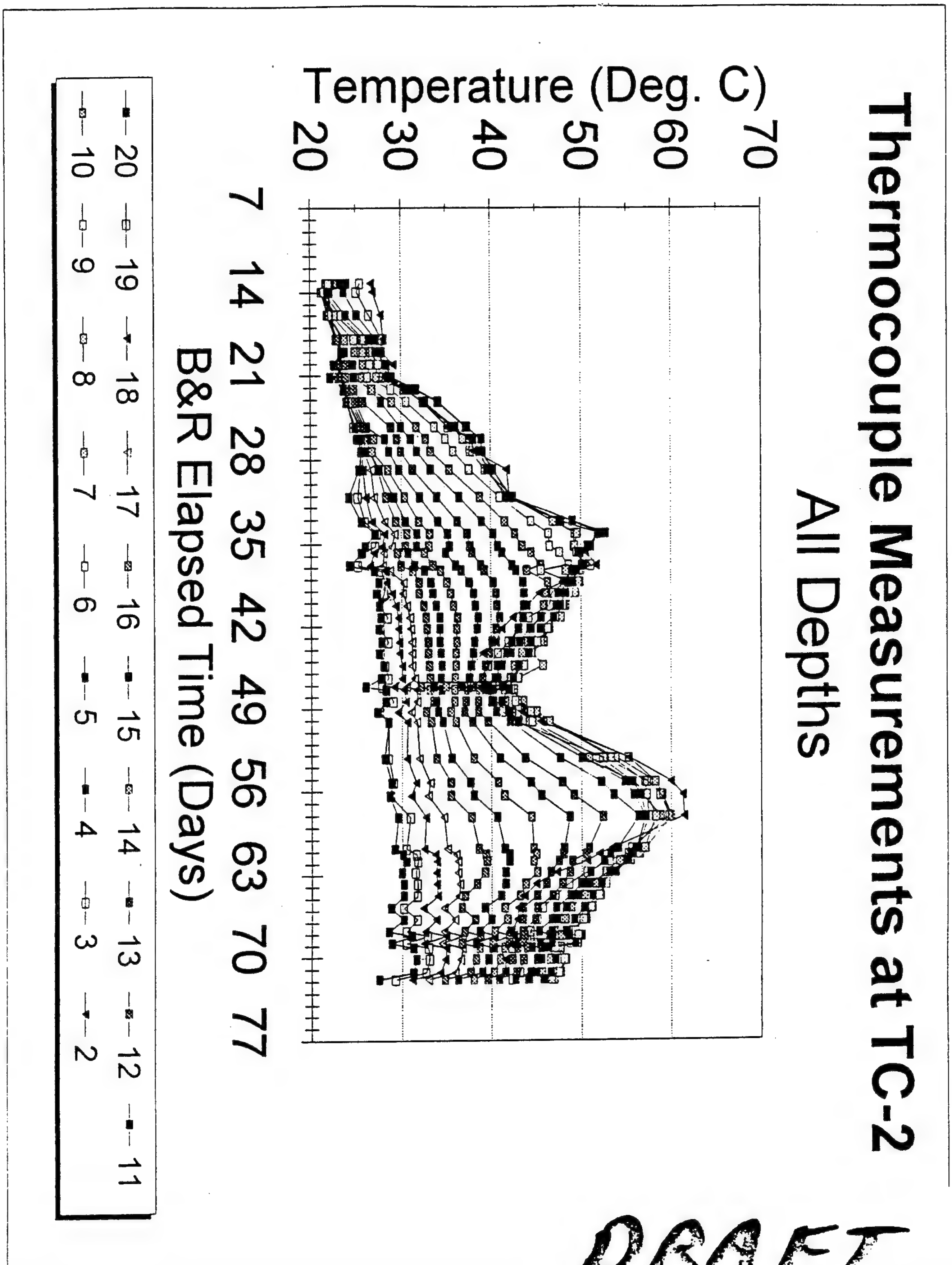
POINT @
CO



Thermocouple Measurements at TC-2
All Depths
Temperature (Deg. C)
20
30
40
50
60
70
7
14
21
28
35
42
49
56
63
70
77
B&R Elapsed Time (Days)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2

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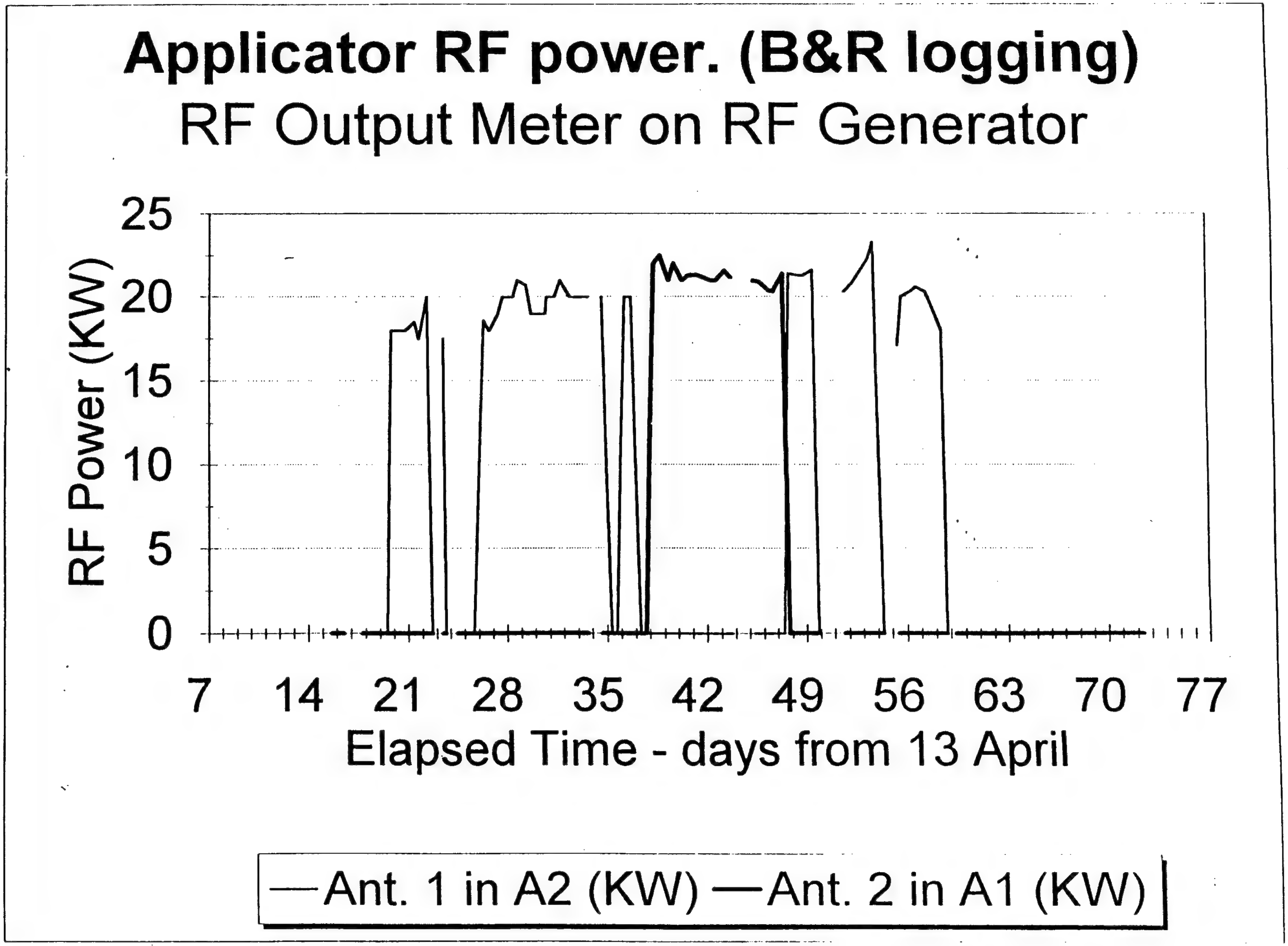


Applicator RF power. (B&R logging)
RF Output Meter on RF Generator
RF Power (KW)
25
20
15
10
5
0
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time - days from 13 April
—Ant. 1 in A2 (KW) —Ant. 2 in A1 (KW)

APPENDIX I - Plots of SVE and RF system data

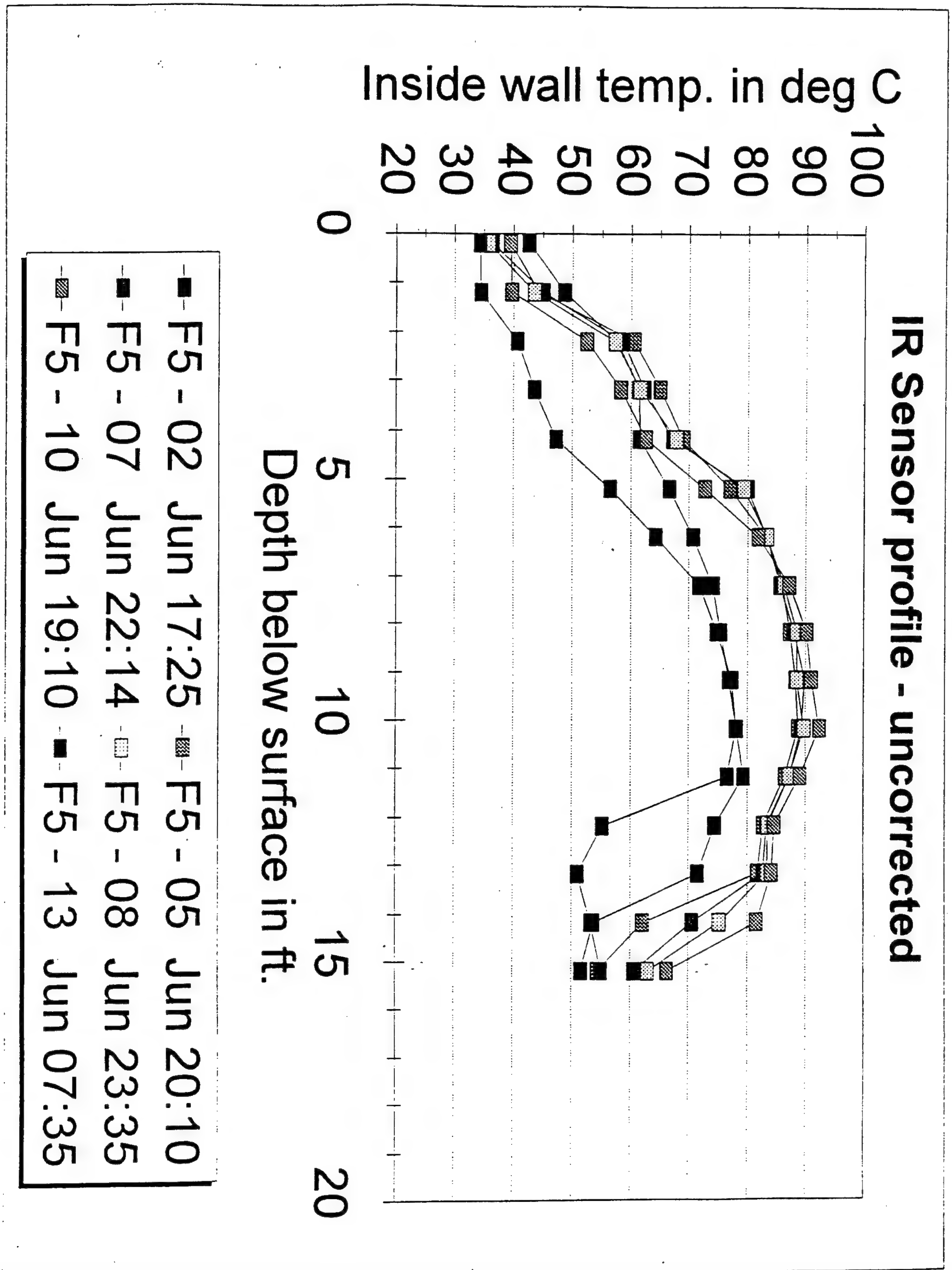
This section presents plots of selected SVE and Heating System data displayed on a time line compatible with the temperature data.

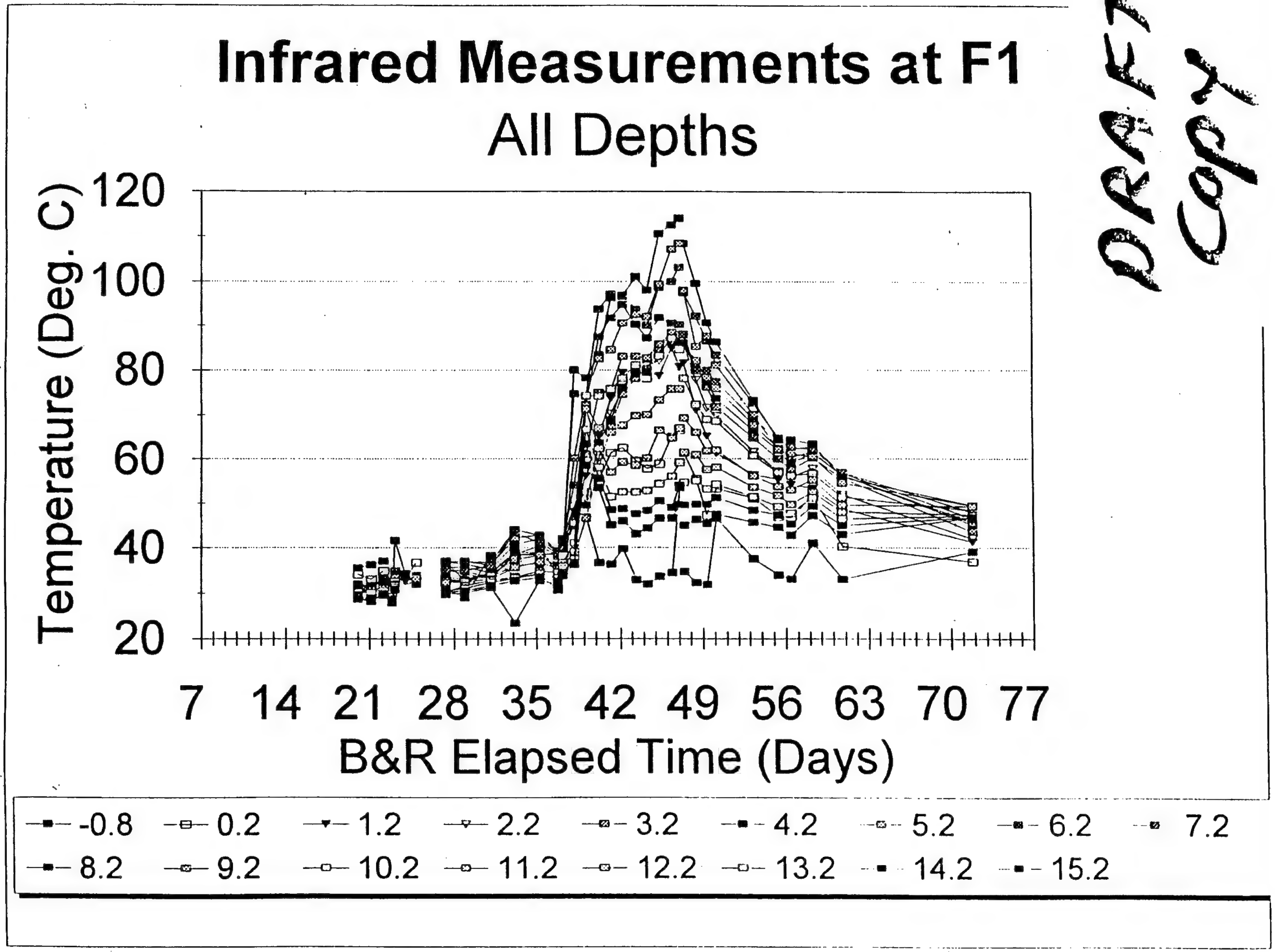
KAI RF HEATING SYSTEM DATA (recorded by B&R personnel)

- Plot of Applicator Wall Fiber optic probes over a 7 to 77 day span
  - Wells A2 and A1
- Plot of Applicator RF power (sampled 1 to 2 times per day)
  - Antenna 1 and Antenna 2 Power Generation

SVE SYSTEM DATA

- Plots of SVE Pressures over a 7 to 77 day span (120 PSI points cut off)
  - Suction, Discharge and Compressor
- Plots of SVE Vacuum over a 7 to 77 day span
  - E1 through E8 extraction wells
  - Center extraction wells E4 and E5
- Plots of SVE Temperatures over a 7 to 77 day span
  - Xmas tree and Mixed Vapor in degrees C
  - E1 through E8 extraction well thermocouple measurements at entrance to the SVE manifold.
  - E4 and E5 extraction well temperatures (10 ft. to 20 ft. screened extraction on the center line between wells A1 and A2).
  - E1, E2 and E3 east side extraction well temperatures


IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F5 - 02 Jun 17:25
F5 - 05 Jun 20:10
F5 - 07 Jun 22:14
F5 - 08 Jun 23:35
F5 - 10 Jun 19:10
F5 - 13 Jun 07:35



Infrared Measurements at F1
All Depths
Temperature (Deg. C)
120
100
80
60
40
20
7
14
21
28
35
42
49
56
63
70
77
B&R Elapsed Time (Days)
-0.8
0.2
1.2
2.2
3.2
4.2
5.2
6.2
7.2
8.2
9.2
10.2
11.2
12.2
13.2
14.2
15.2

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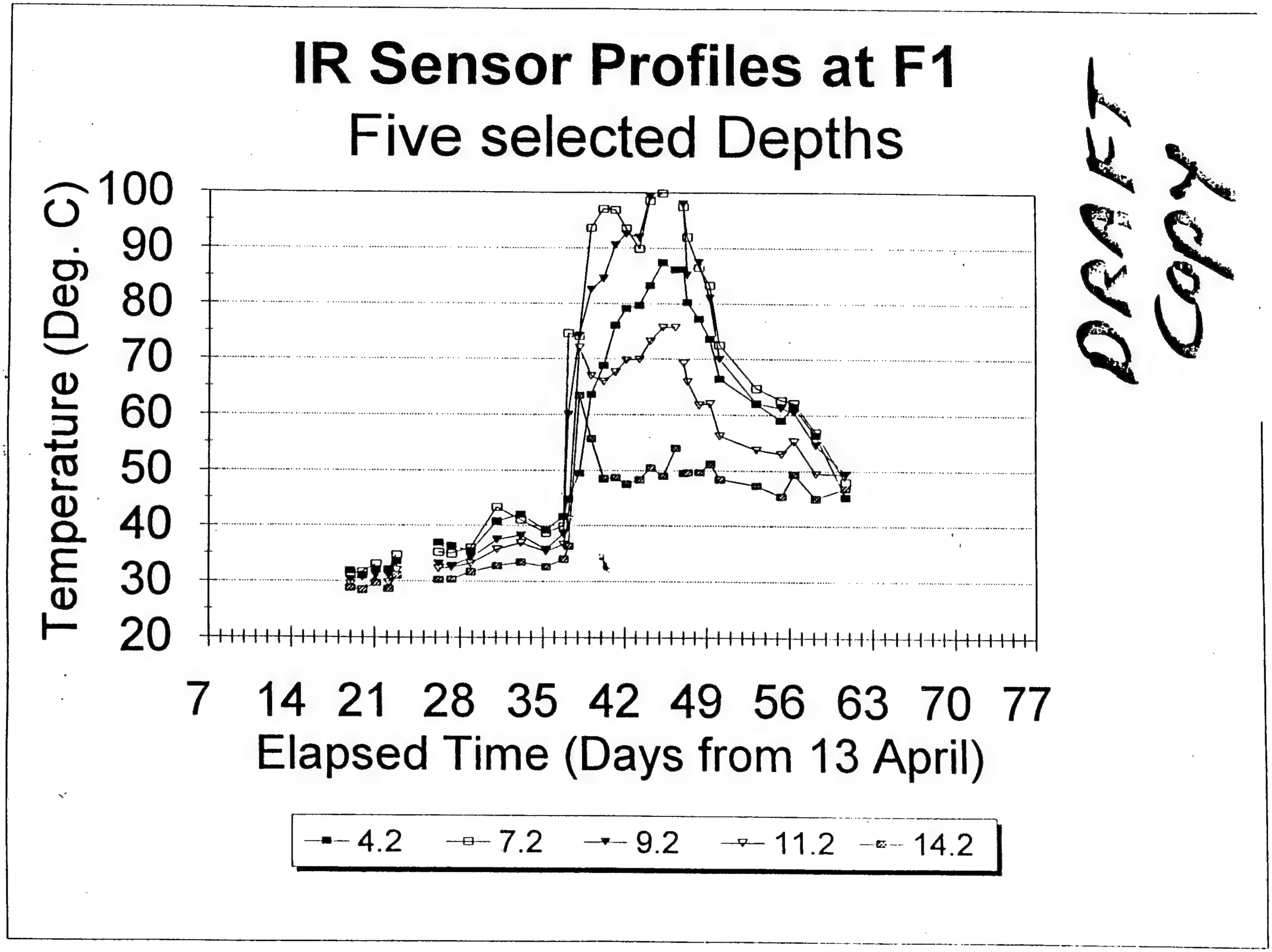
IR Sensor Profiles at F1
Five selected Depths
Temperature (Deg. C)
100
90
80
70
60
50
40
30
20
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time (Days from 13 April)
4.2
7.2
9.2
11.2
14.2
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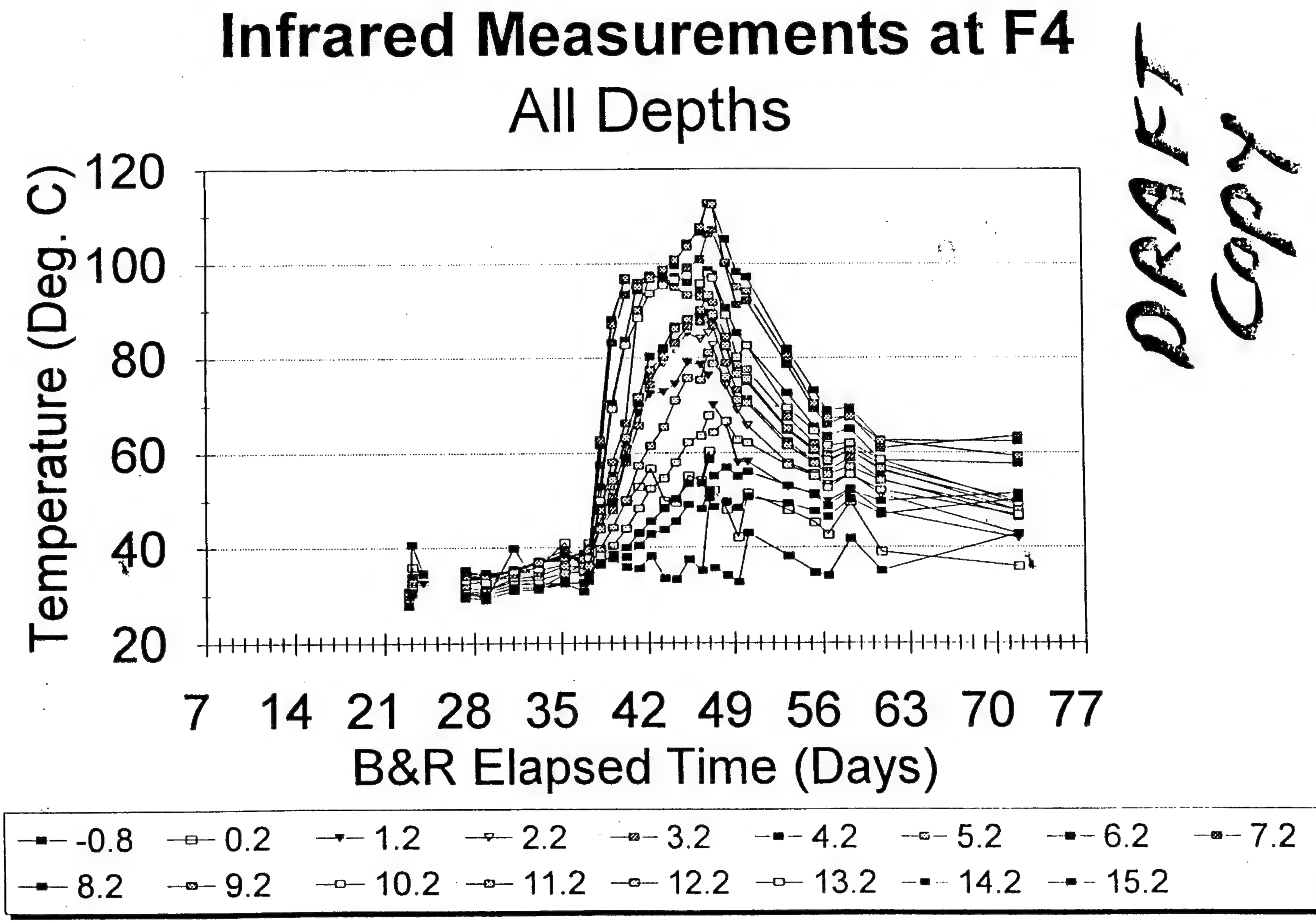
Infrared Measurements at F4
All Depths
Temperature (Deg. C)
120
100
80
60
40
20
7
14
21
28
35
42
49
56
63
70
77
B&R Elapsed Time (Days)
-0.8
0.2
1.2
2.2
3.2
4.2
5.2
6.2
7.2
8.2
9.2
10.2
11.2
12.2
13.2
14.2
15.2

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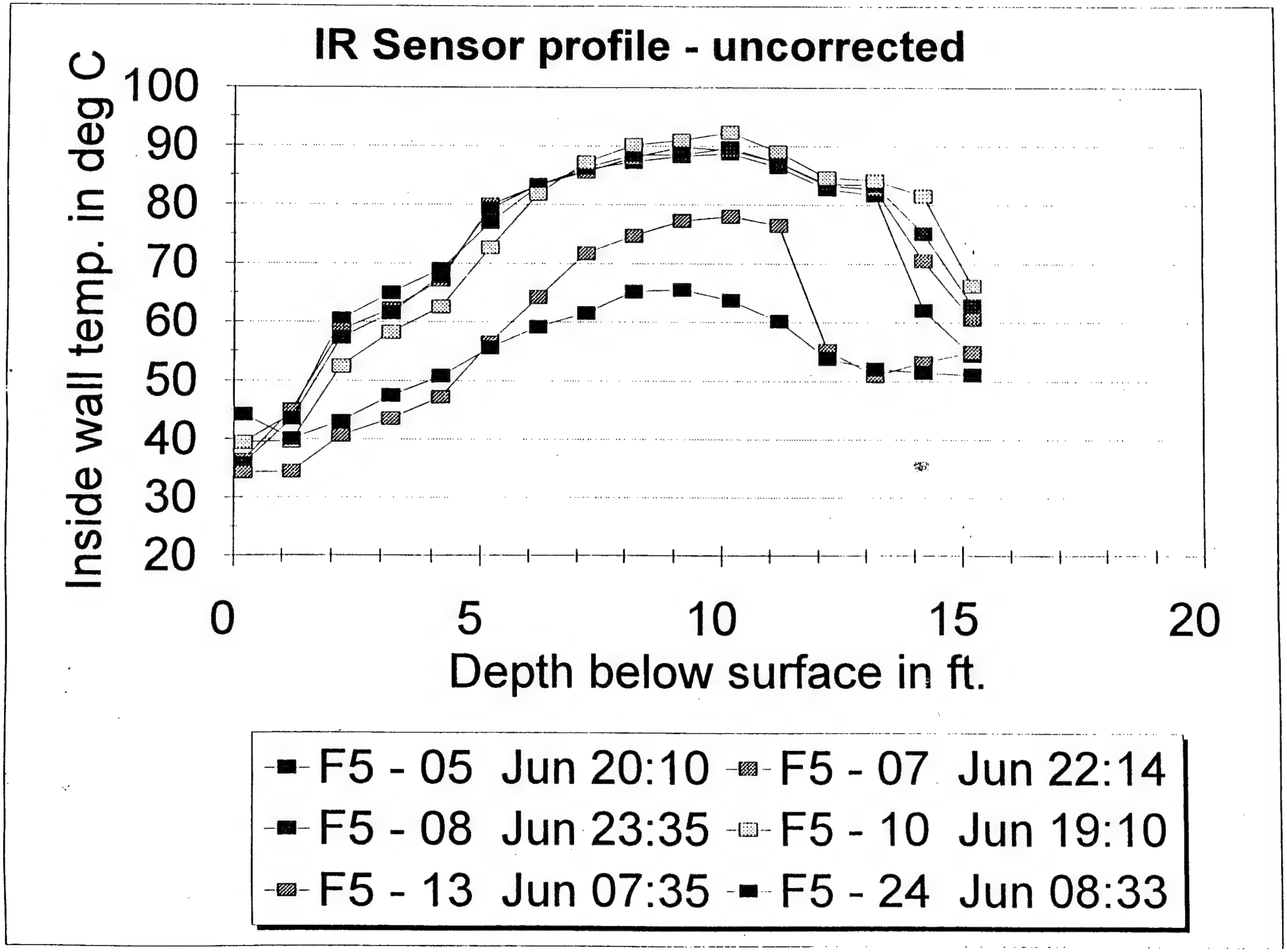
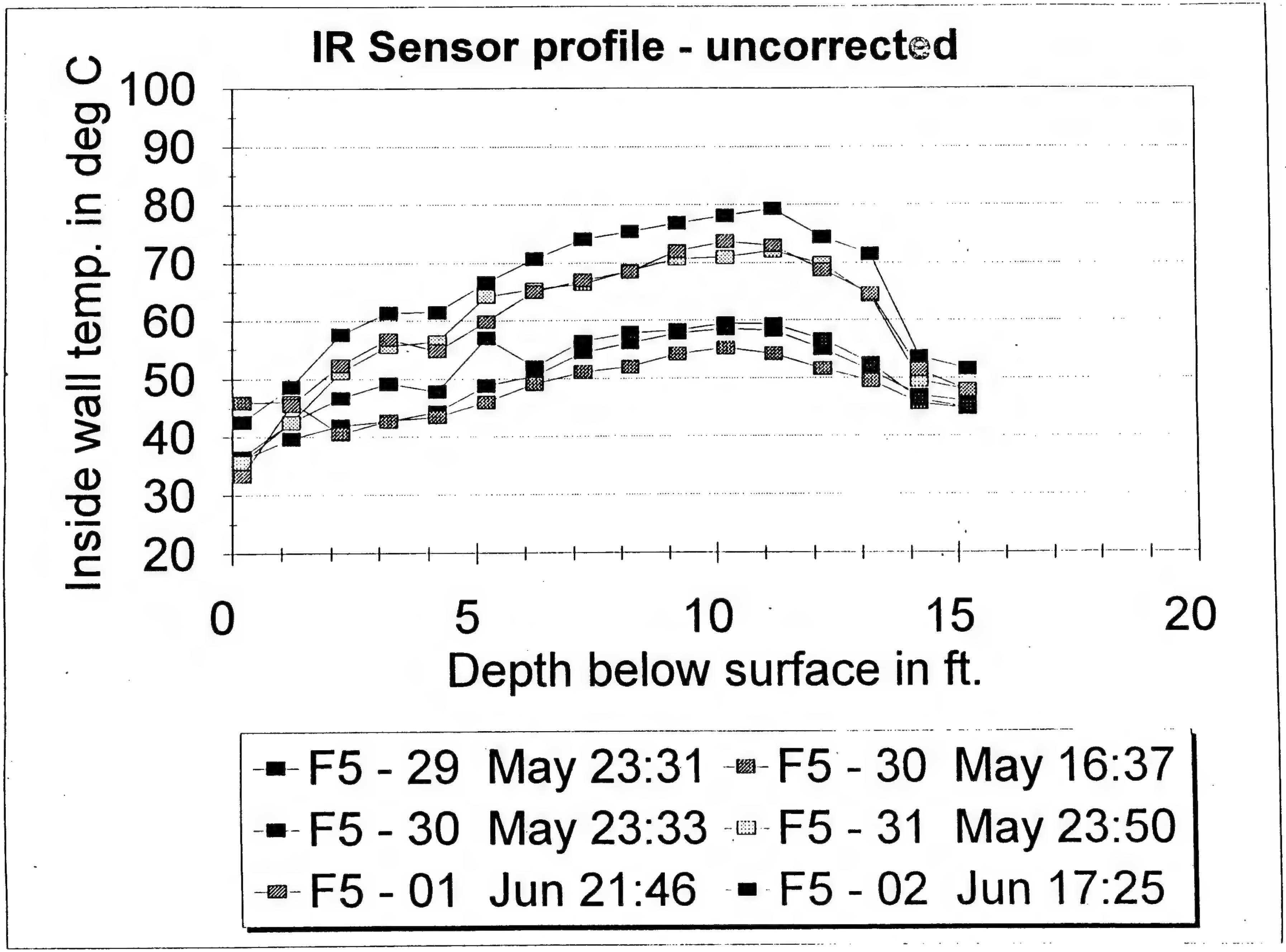
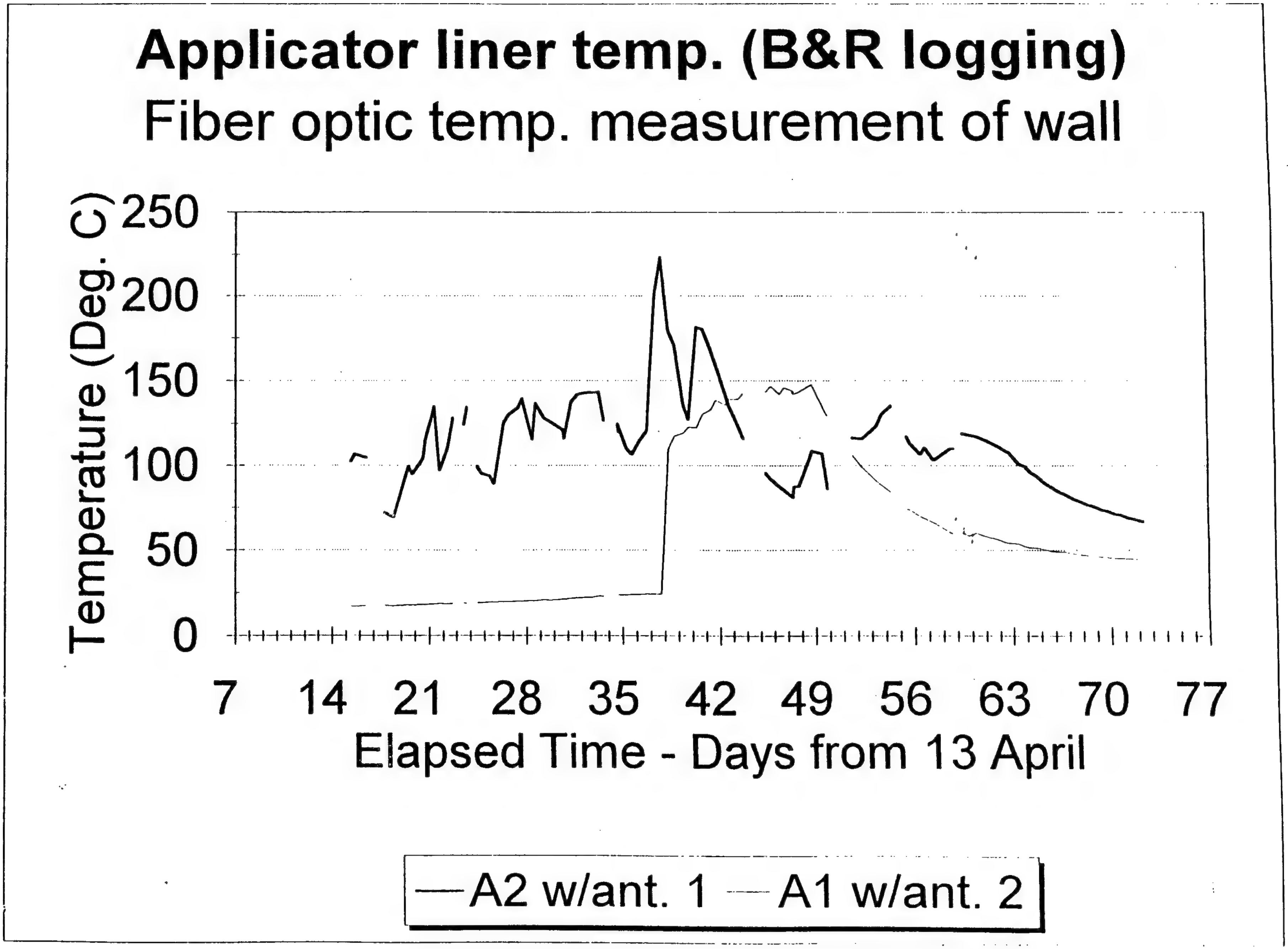
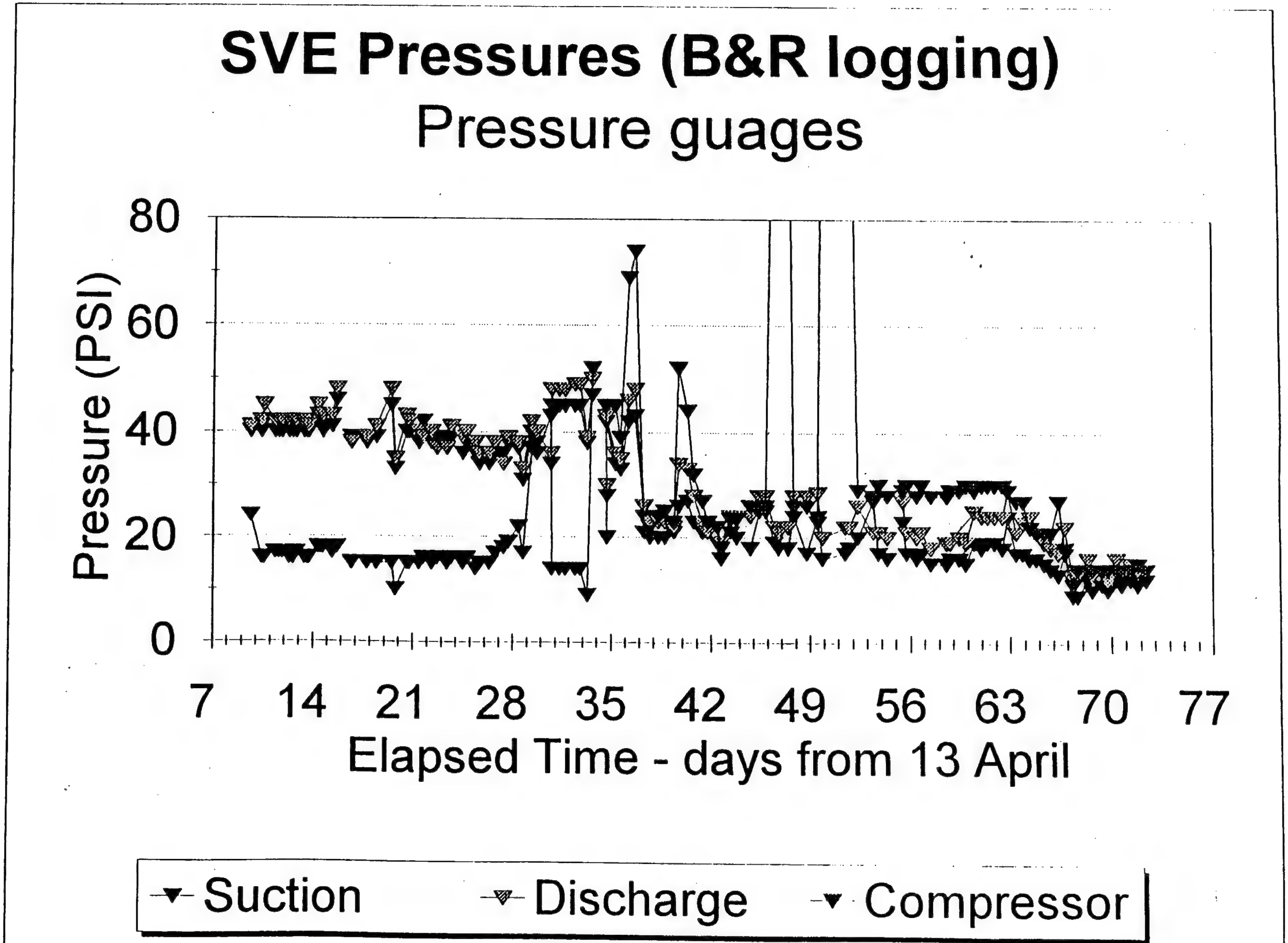
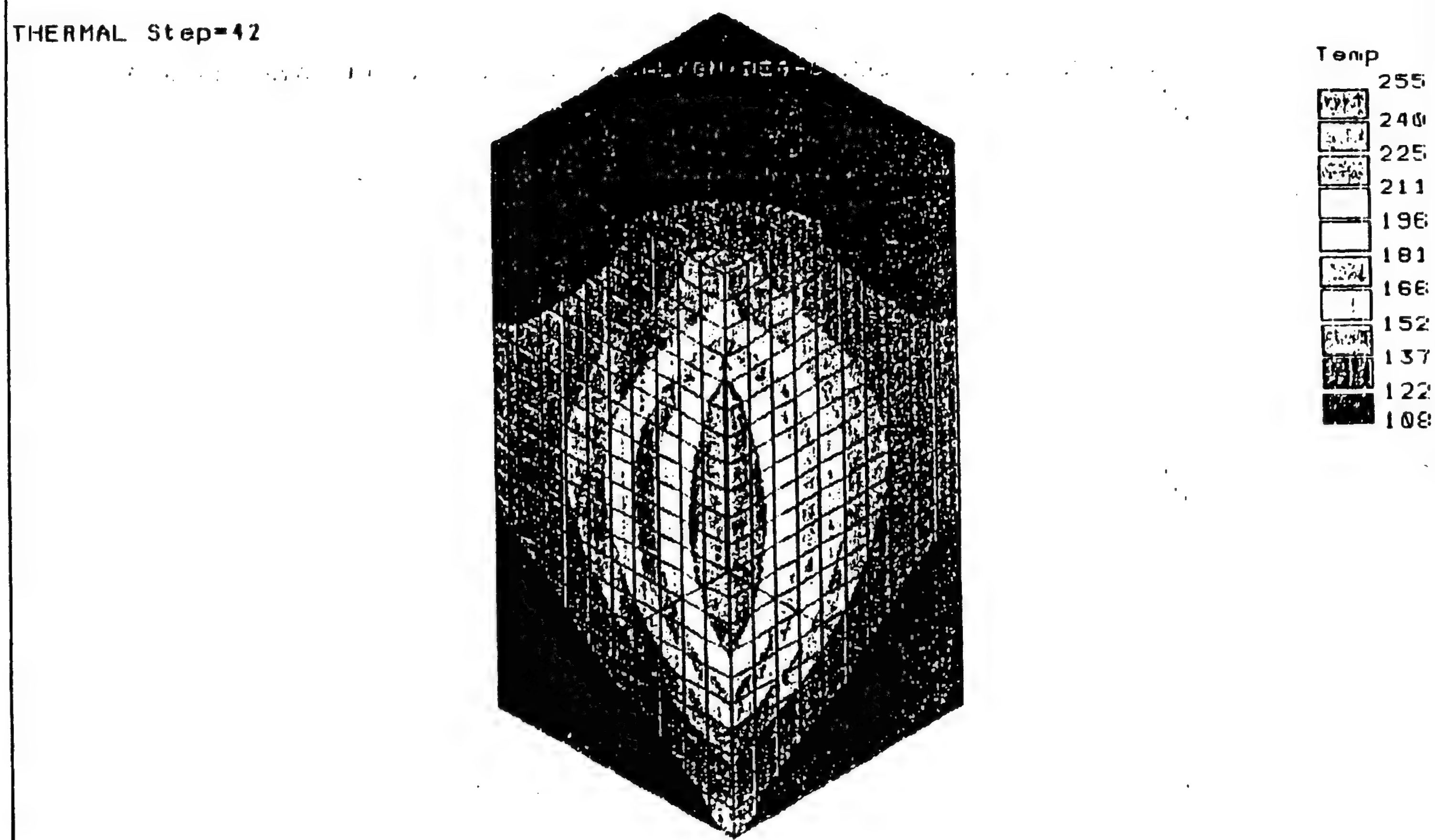

IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F5 - 05 Jun 20:10
F5 - 07 Jun 22:14
F5 - 08 Jun 23:35
F5 - 10 Jun 19:10
F5 - 13 Jun 07:35
F5 - 24 Jun 08:33

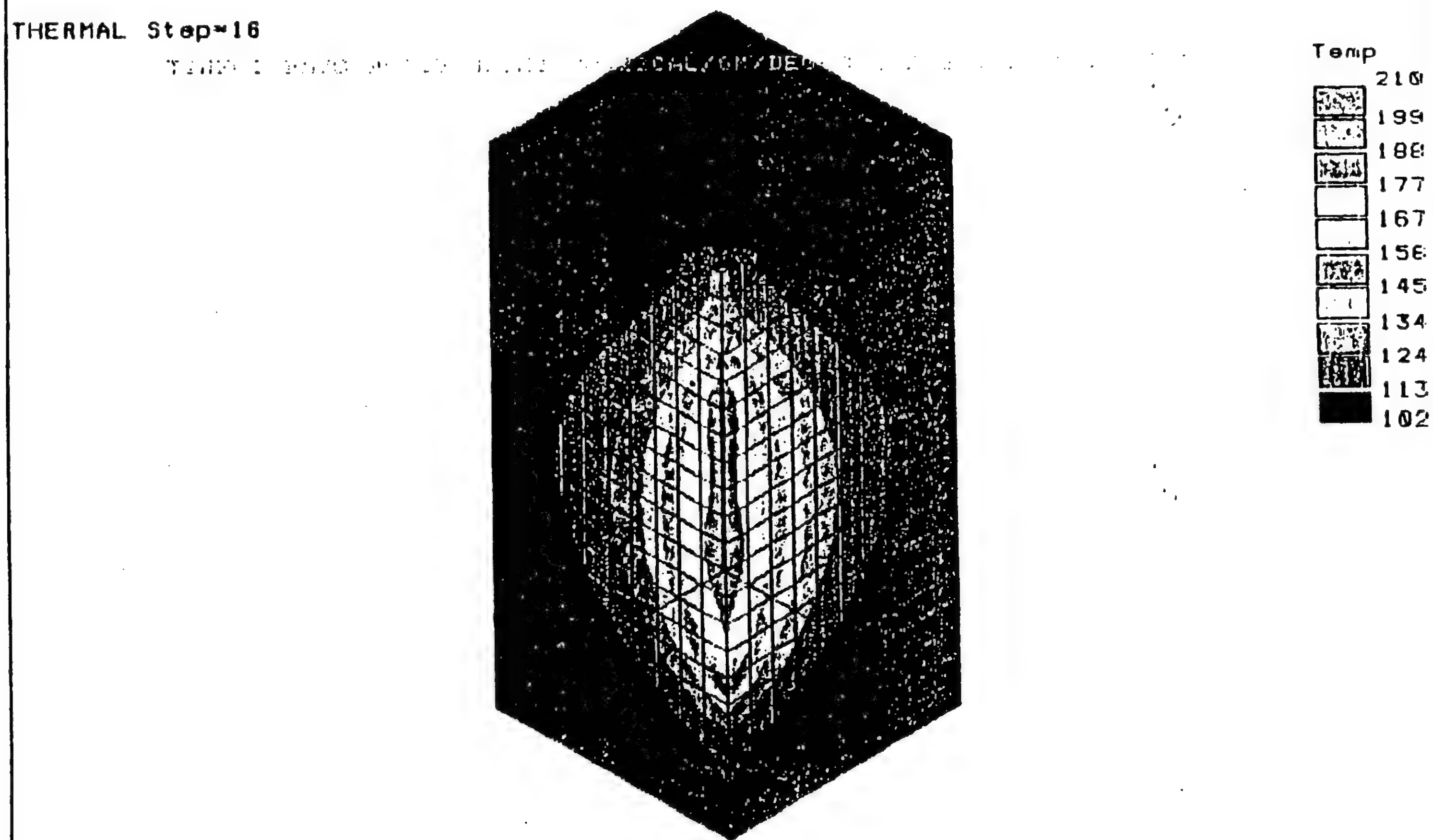

IR Sensor profile - uncorrected
Inside wall temp. in deg C
100
90
80
70
60
50
40
30
20
0
5
10
15
20
Depth below surface in ft.
F5 - 29 May 23:31
F5 - 30 May 16:37
F5 - 30 May 23:33
F5 - 31 May 23:50
F5 - 01 Jun 21:46
F5 - 02 Jun 17:25


Applicator liner temp. (B&R logging)
Fiber optic temp. measurement of wall
Temperature (Deg. C)
250
200
150
100
50
0
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time - Days from 13 April
A2 w/ant. 1
A1 w/ant. 2

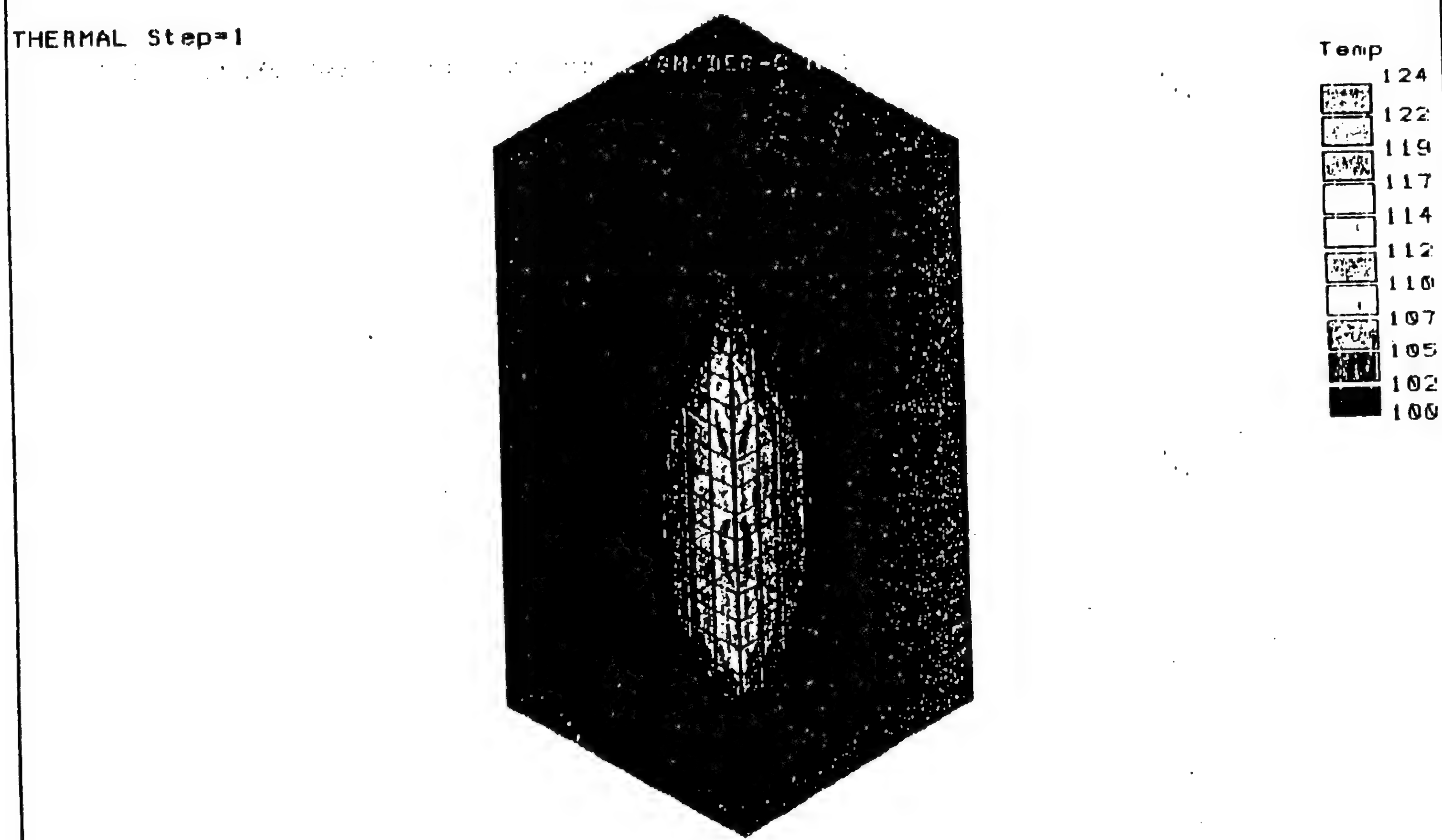

SVE Pressures (B&R logging)
Pressure guages
Pressure (PSI)
80
60
40
20
0
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time - days from 13 April
Suction
Discharge
Compressor



SGL.G06 **Single Applicator** Temperature Profile - After 21 days of RF heating



SGL.G04 **Single Applicator** Temperature Profile - After 8 days of RF heating



SGL.G02 **Single Applicator** Temperature Profile - After 0.5 days of RF heating

APPENDIX J - Thermal Modeling Data

The following charts are the 3-D color (4-D) output plots from the COSMOS FEA thermal modeling program. *The model asssumes homogenous soil and constant heating.*

Note: The origin of the coordinate system is at the center of the block. The heating applicators are positioned vertically. The z direction is vertical.

Designation Description

20 kW average power level

SGL.G01 Single Applicator Temperature vs. Time - 5' radially away from feed
SGL.G02 Single Applicator Temperature Profile - After 0.5 days of RF heating
SGL.G03 Single Applicator Temperature Profile - After 4 days of RF heating
SGL.G04 Single Applicator Temperature Profile - After 8 days of RF heating
SGL.G05 Single Applicator Temperature Profile - After 15 days of RF heating
SGL.G06 Single Applicator Temperature Profile - After 21 days of RF heating
SGL.G07 Single Applicator Temperature Profile - After 27 days of RF heating
SGL.G08 Single Applicator Temperature Profile - After 30 days of RF heating

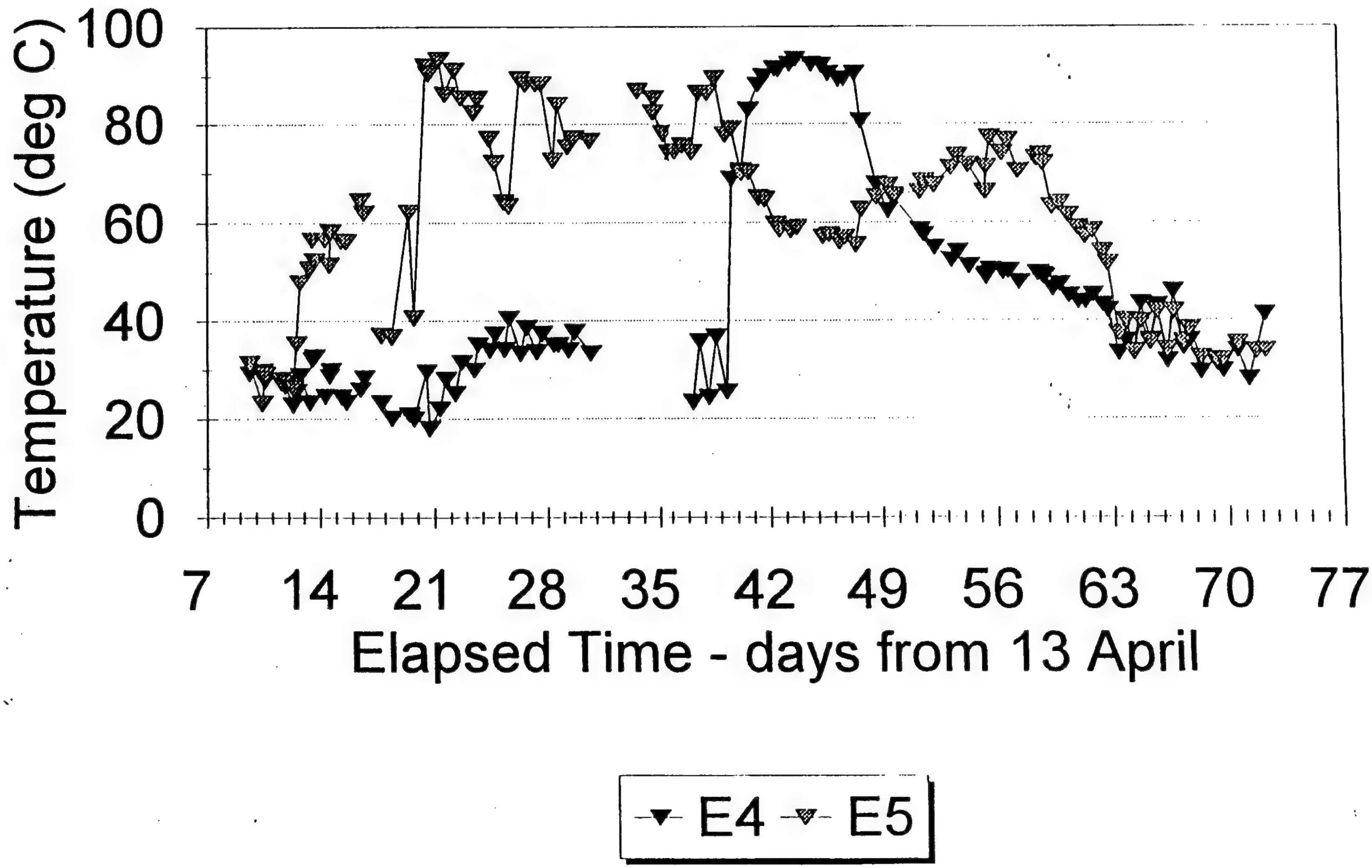
10 kW average power to each applicator with a combined power of 20 kW

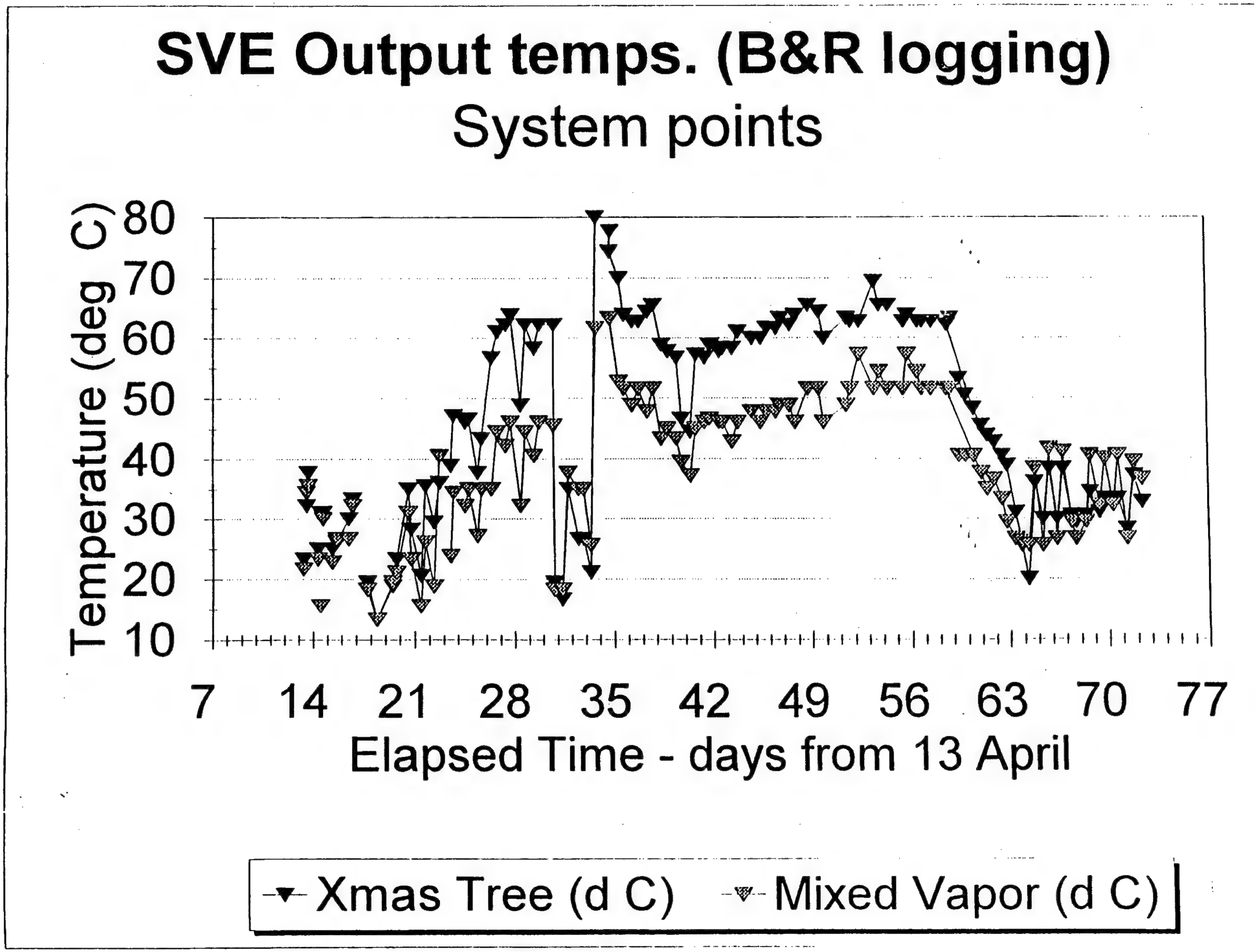
1/4 volume removed view
DBL.G01 Dual Applicators Temperature vs. Time - 5' radially away from feed
DBL.G02 Dual applicators Temperature Profile - After 0.5 days of RF heating
DBL.G03 Dual Applicators Temperature Profile - After 6 days of RF heating
DBL.G04 Dual Applicators Temperature Profile - After 11 days of RF heating
DBL.G05 Dual Applicators Temperature Profile - After 17 days of RF heating
DBL.G06 Dual Applicators Temperature Profile - After 23 days of RF heating
DBL.G07 Dual Applicators Temperature Profile - After 29 days of RF heating
DBL.G08 Dual Applicators Temperature Profile - After 30 days of RF heating

1/2 volume removed view (side pattern profile)
DBL.G09 Dual applicators Temperature Profile - After 0.5 days of RF heating
DBL.G10 Dual Applicators Temperature Profile - After 6 days of RF heating
DBL.G11 Dual Applicators Temperature Profile - After 11 days of RF heating
DBL.G12 Dual Applicators Temperature Profile - After 17 days of RF heating
DBL.G13 Dual Applicators Temperature Profile - After 23 days of RF heating
DBL.G14 Dual Applicators Temperature Profile - After 29 days of RF heating
DBL.G15 Dual Applicators Temperature Profile - After 30 days of RF heating

SVE Output temps. (B&R logging)

Center extraction well output temps

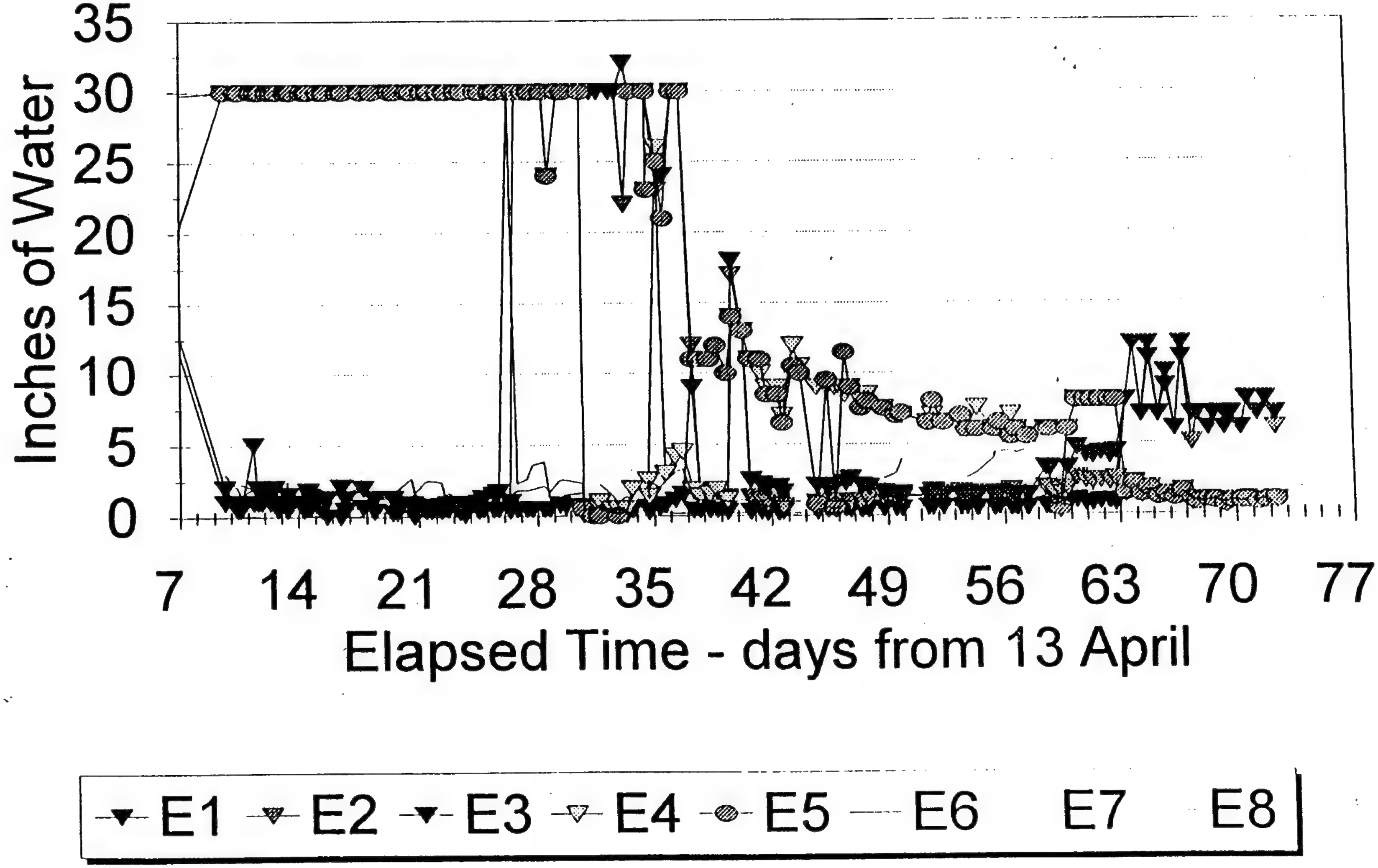


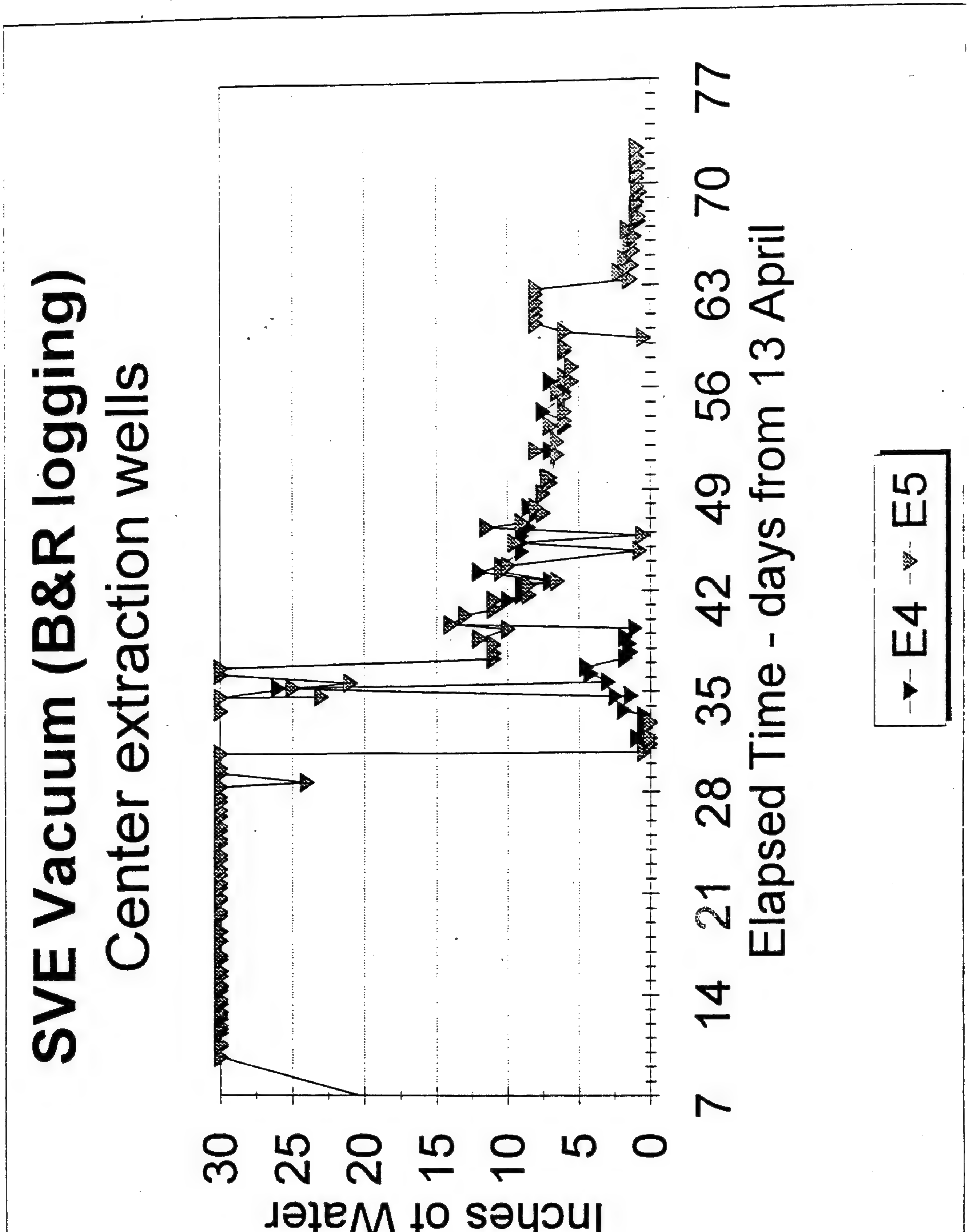


SVE Output temps. (B&R logging)
System points
Temperature (deg C)
80
70
60
50
40
30
20
10
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time - days from 13 April
Xmas Tree (d C)
Mixed Vapor (d C)

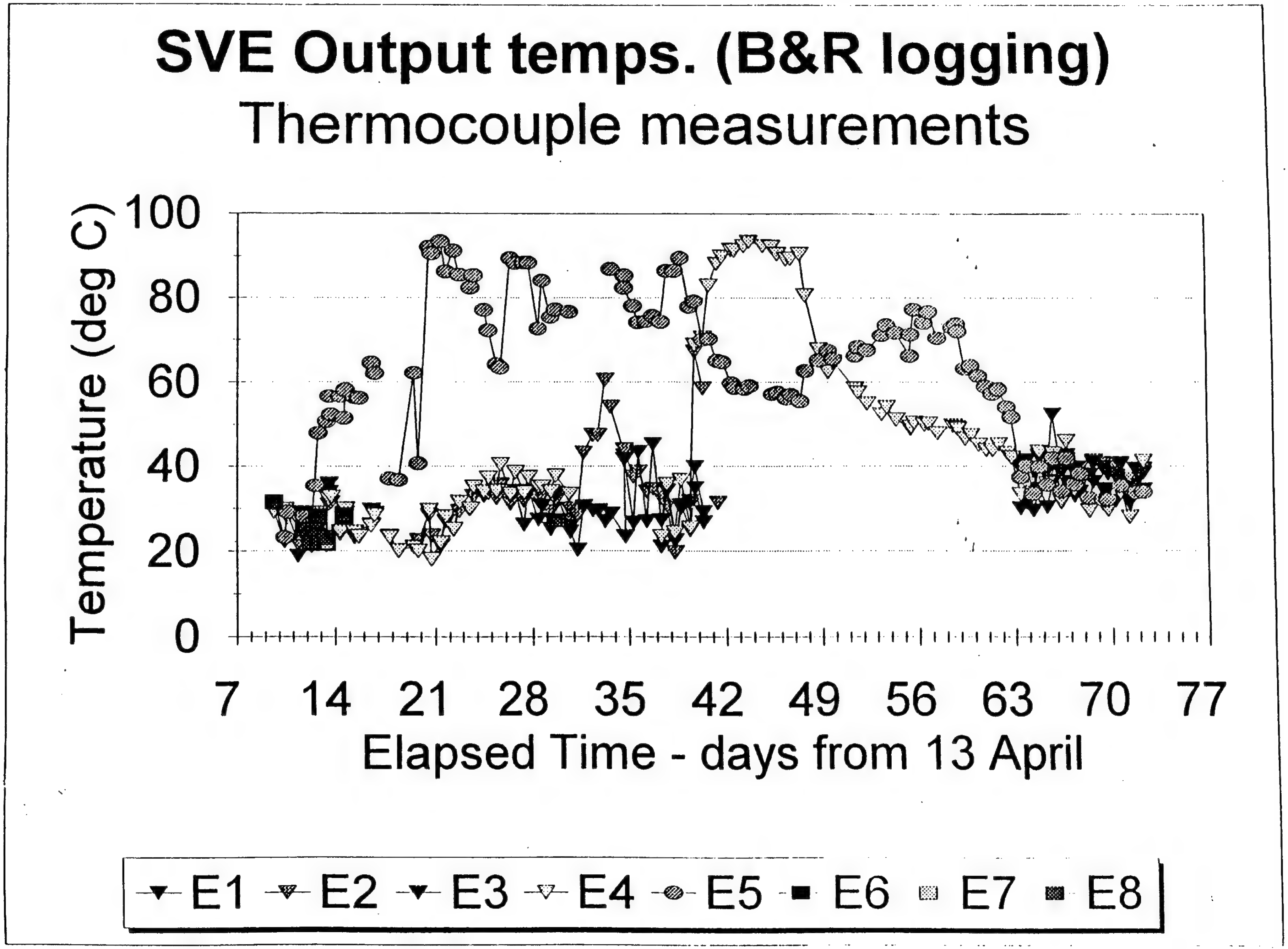
SVE Vacuum (B&R logging)

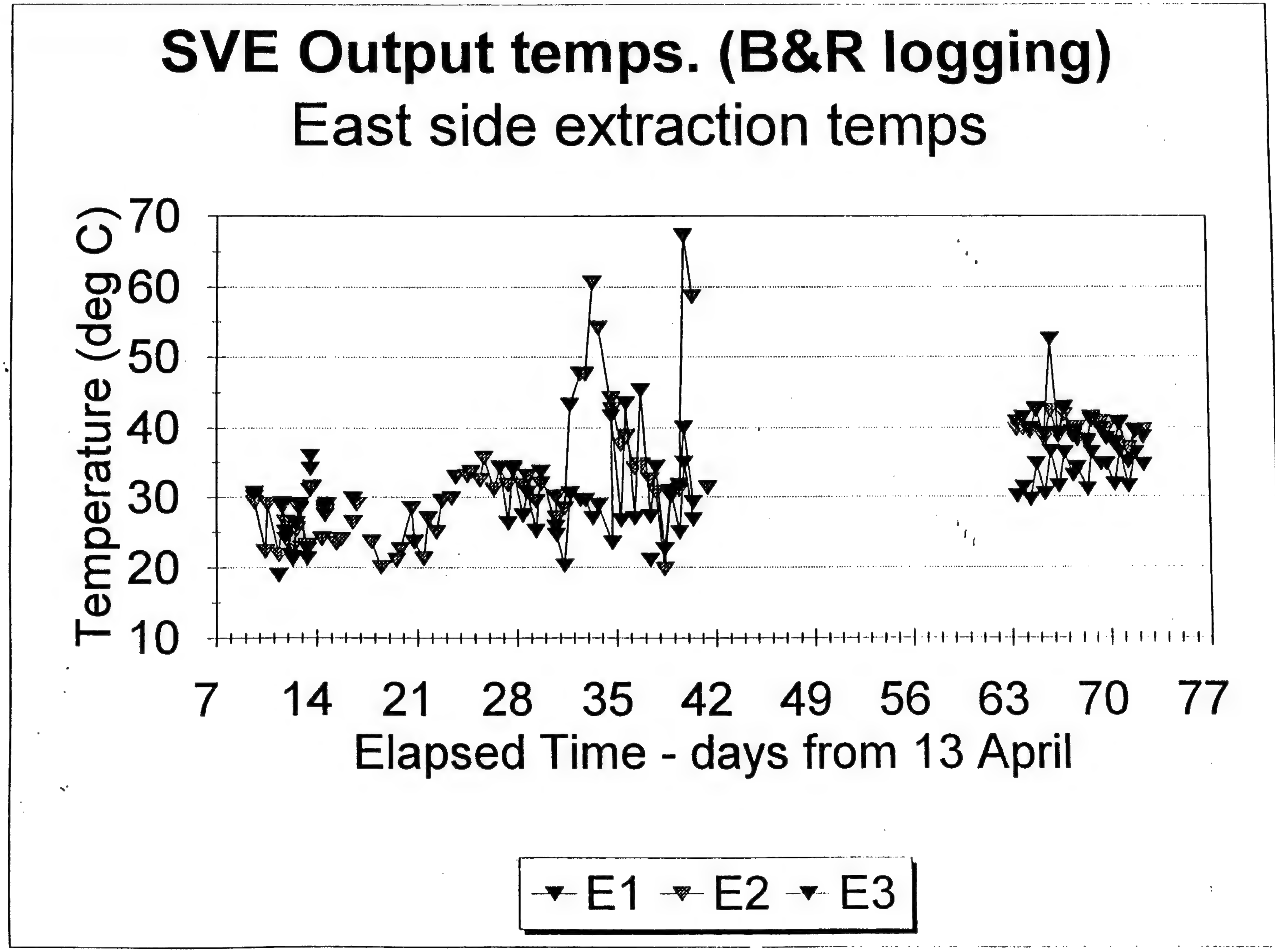
Magnehelic gages

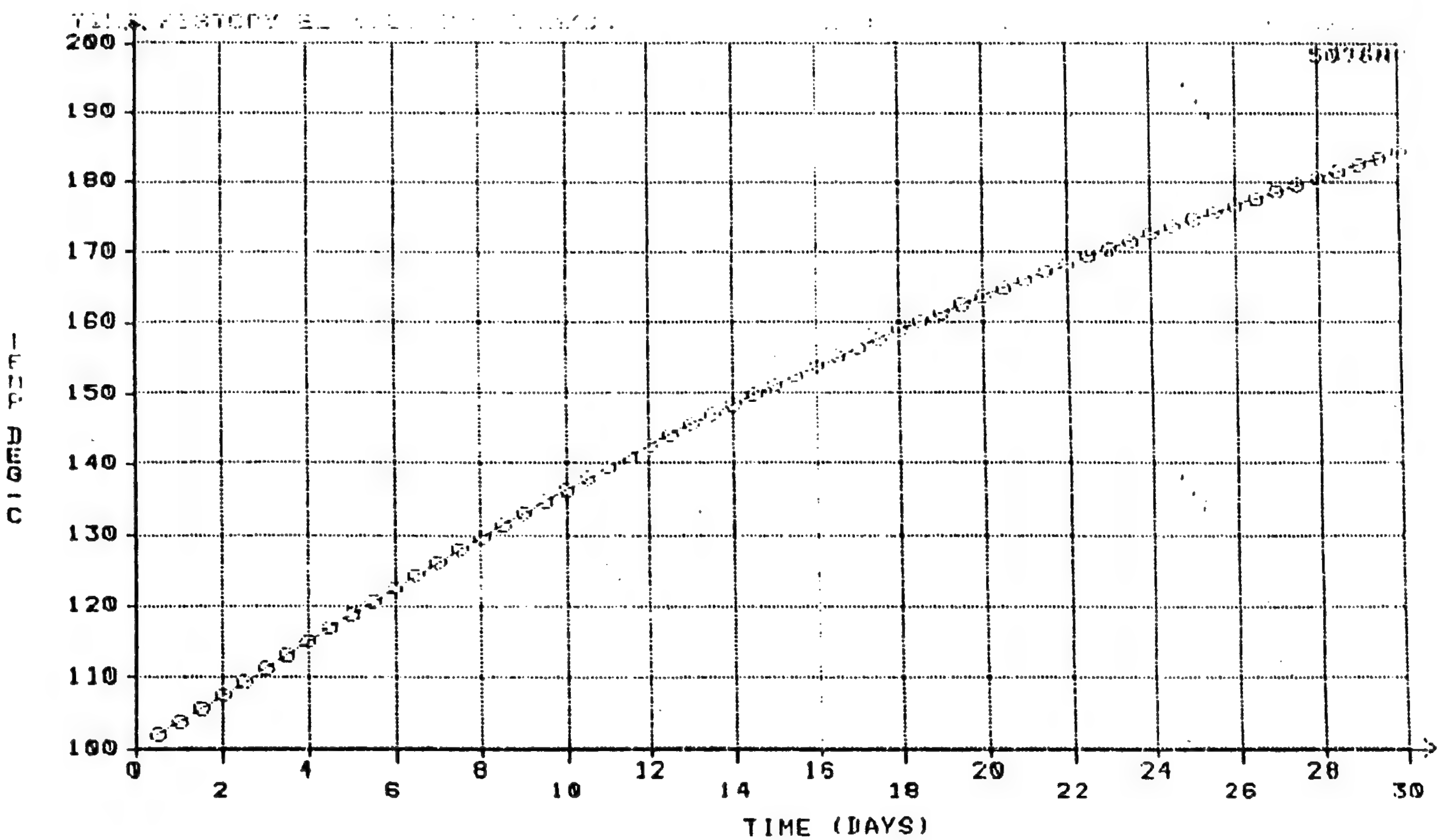




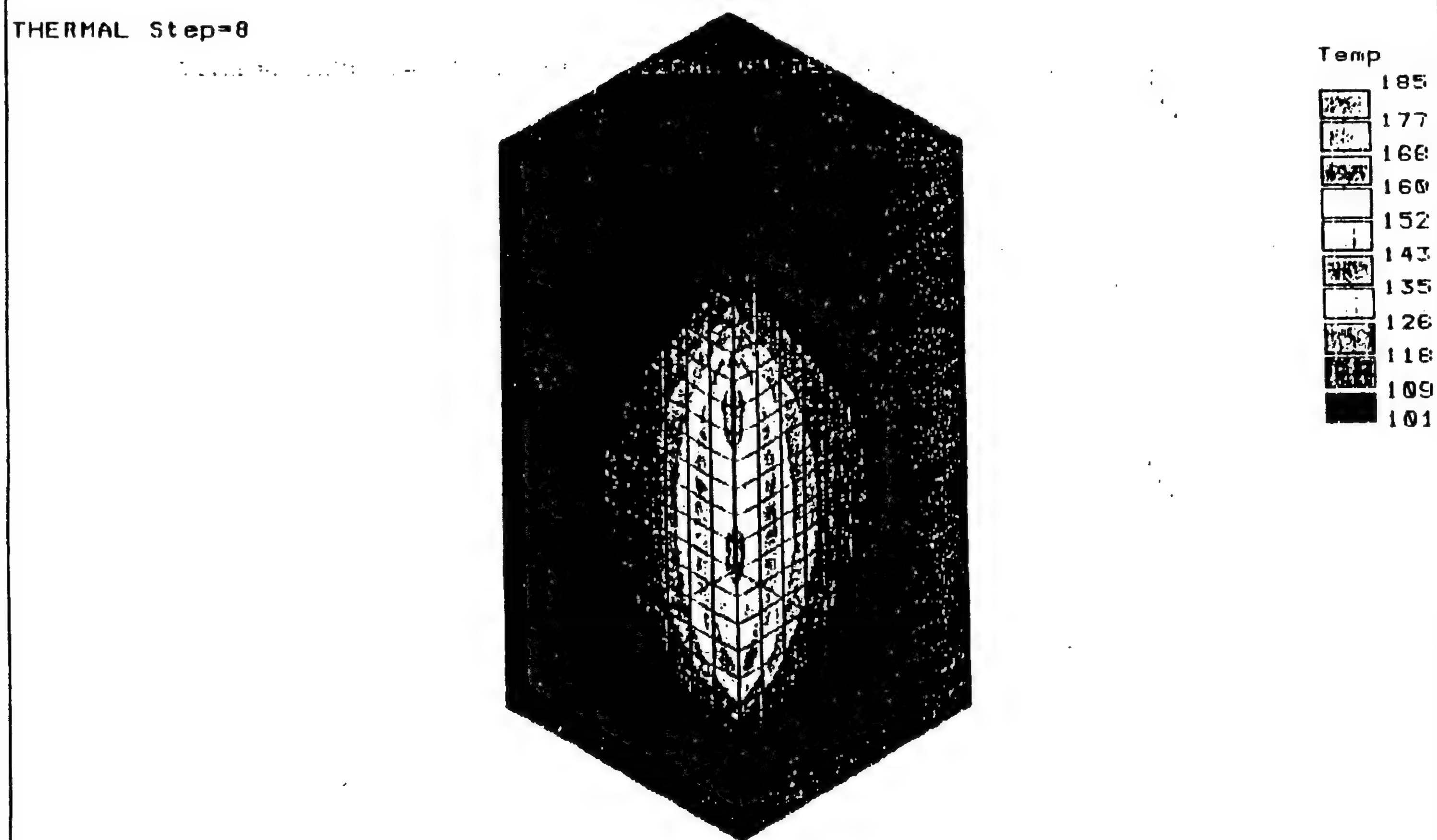
SVE Vacuum (B&R logging)
Center extraction wells
Inches of Water
30
25
20
15
10
5
0
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time - days from 13 April
E4
E5


SVE Output temps. (B&R logging)
Thermocouple measurements
Temperature (deg C)
100
80
60
40
20
0
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time - days from 13 April
E1
E2
E3
E4
E5
E6
E7
E8

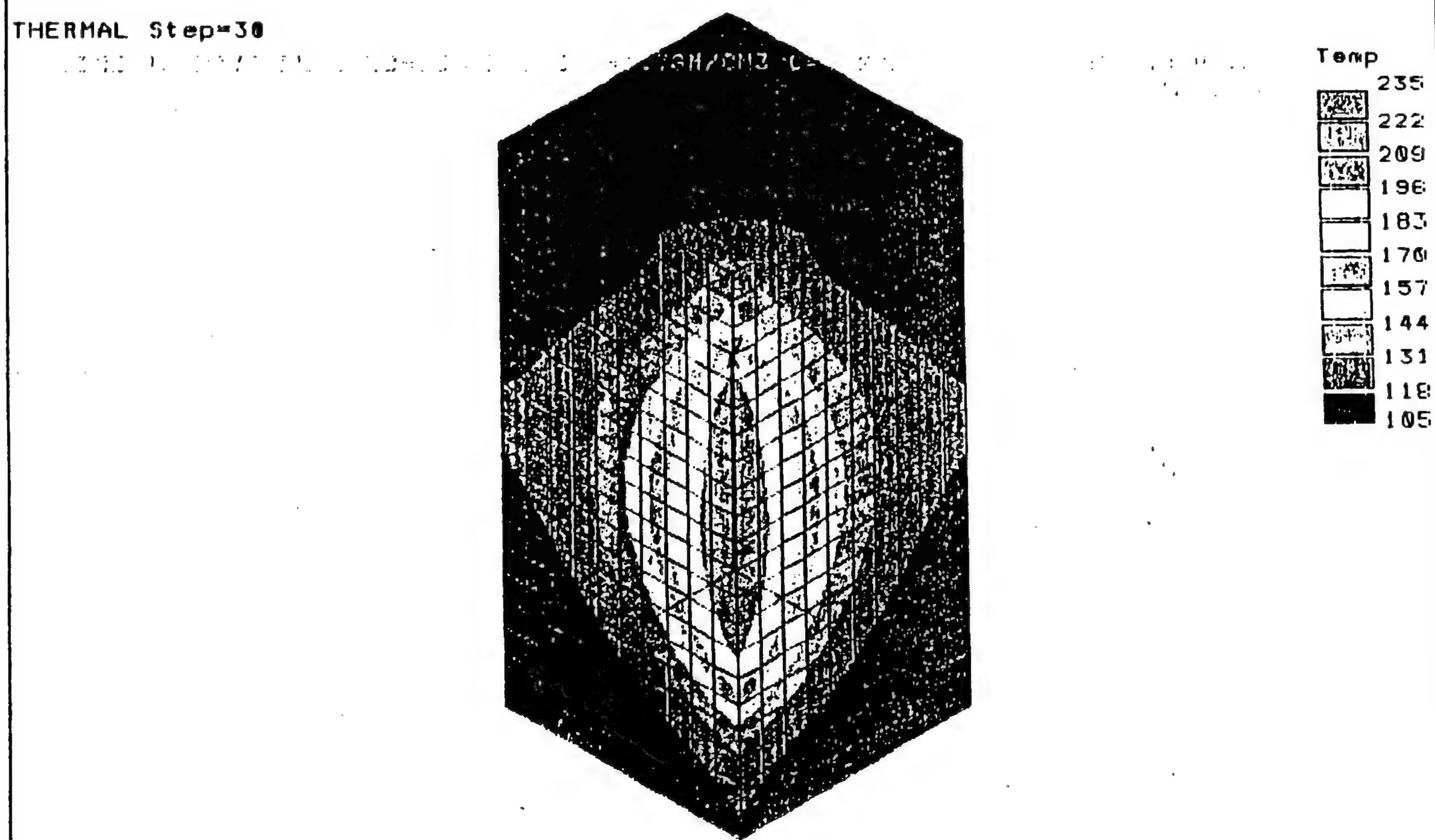

SVE Output temps. (B&R logging)
East side extraction temps
Temperature (deg C)
10
20
30
40
50
60
70
7
14
21
28
35
42
49
56
63
70
77
Elapsed Time - days from 13 April
E1
E2
E3



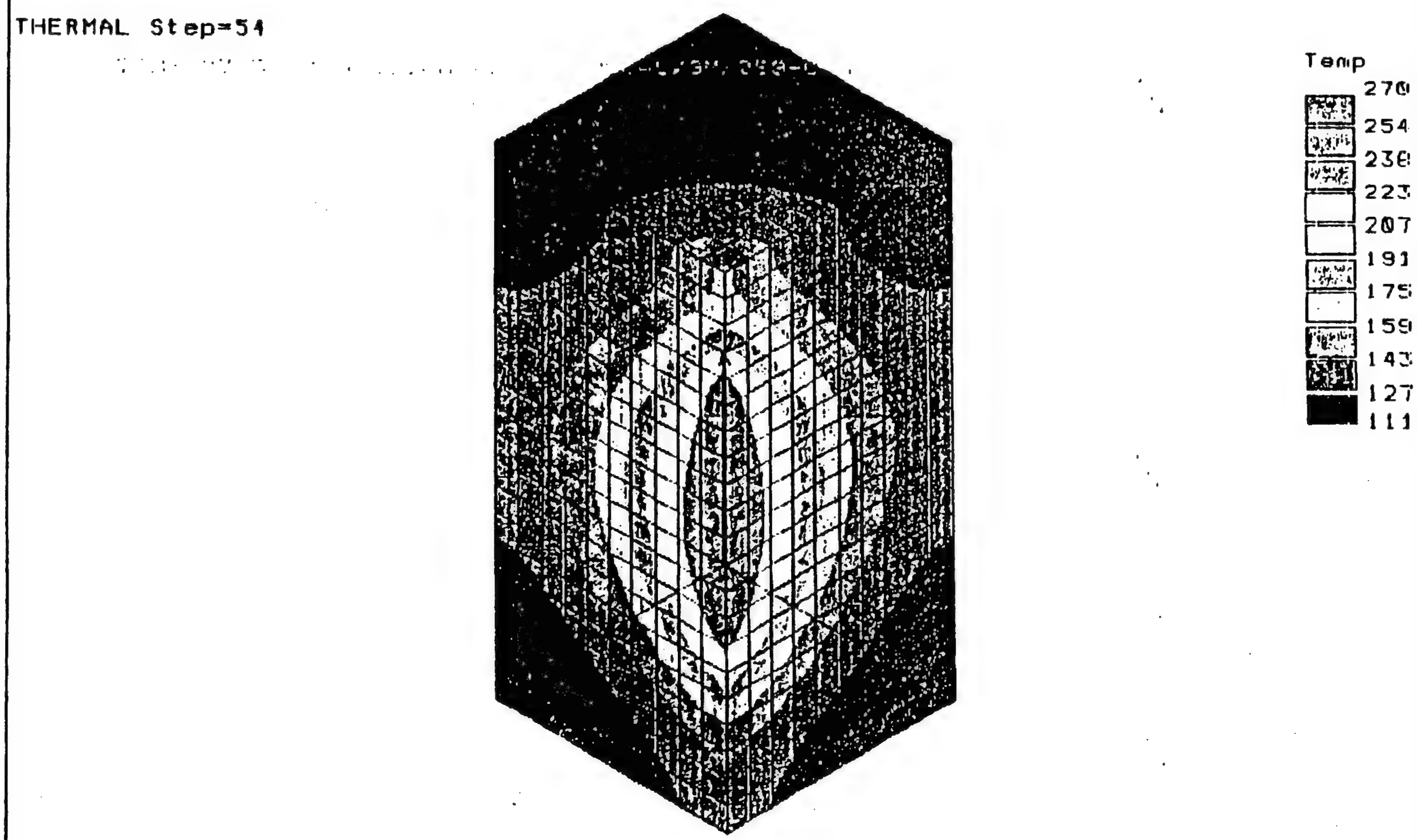
SGL.G01 **Single Applicator** Temperature vs. Time - 5' radially away from feed



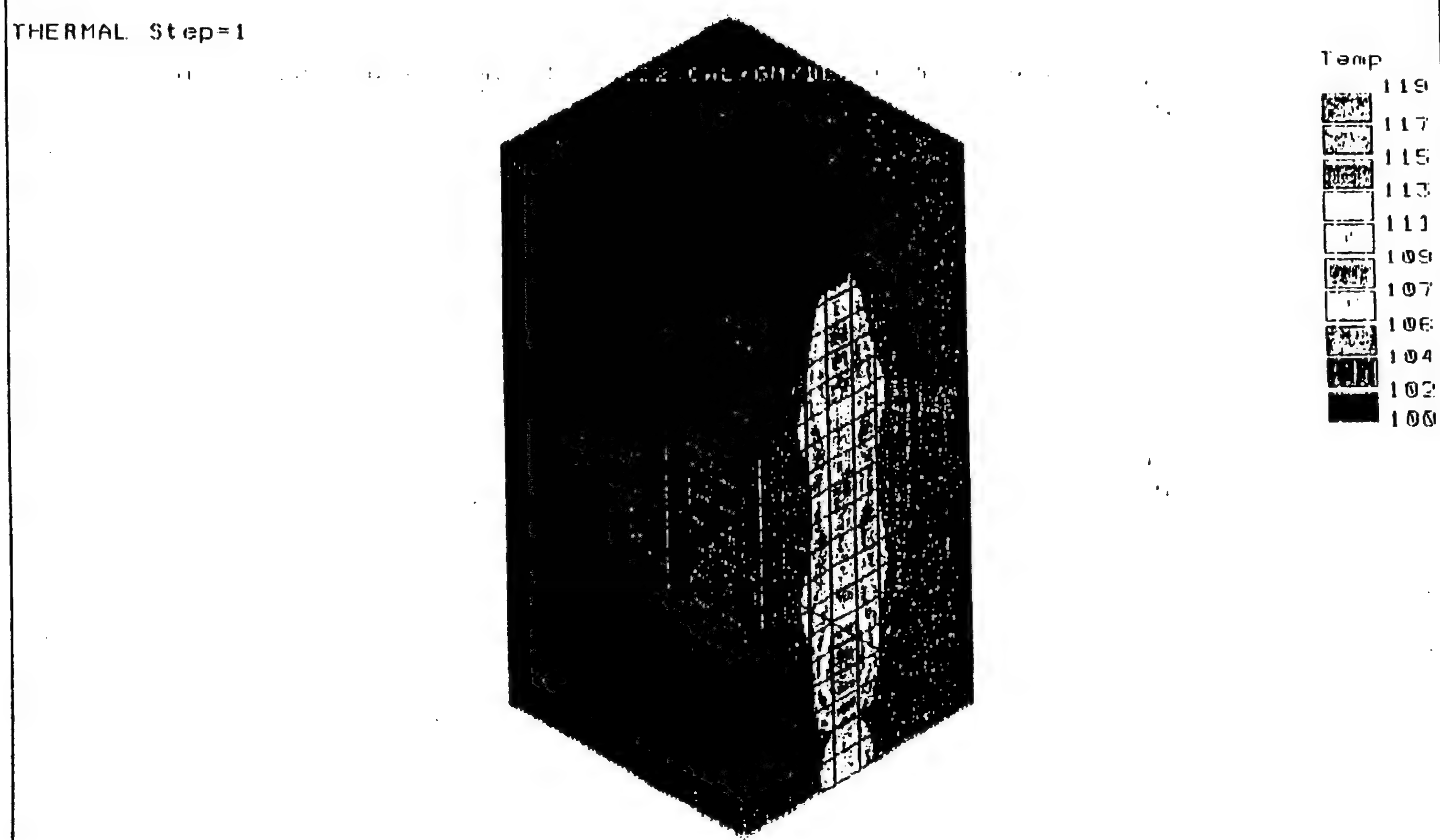
SGL.G03 **Single Applicator** Temperature Profile - After 4 days of RF heating



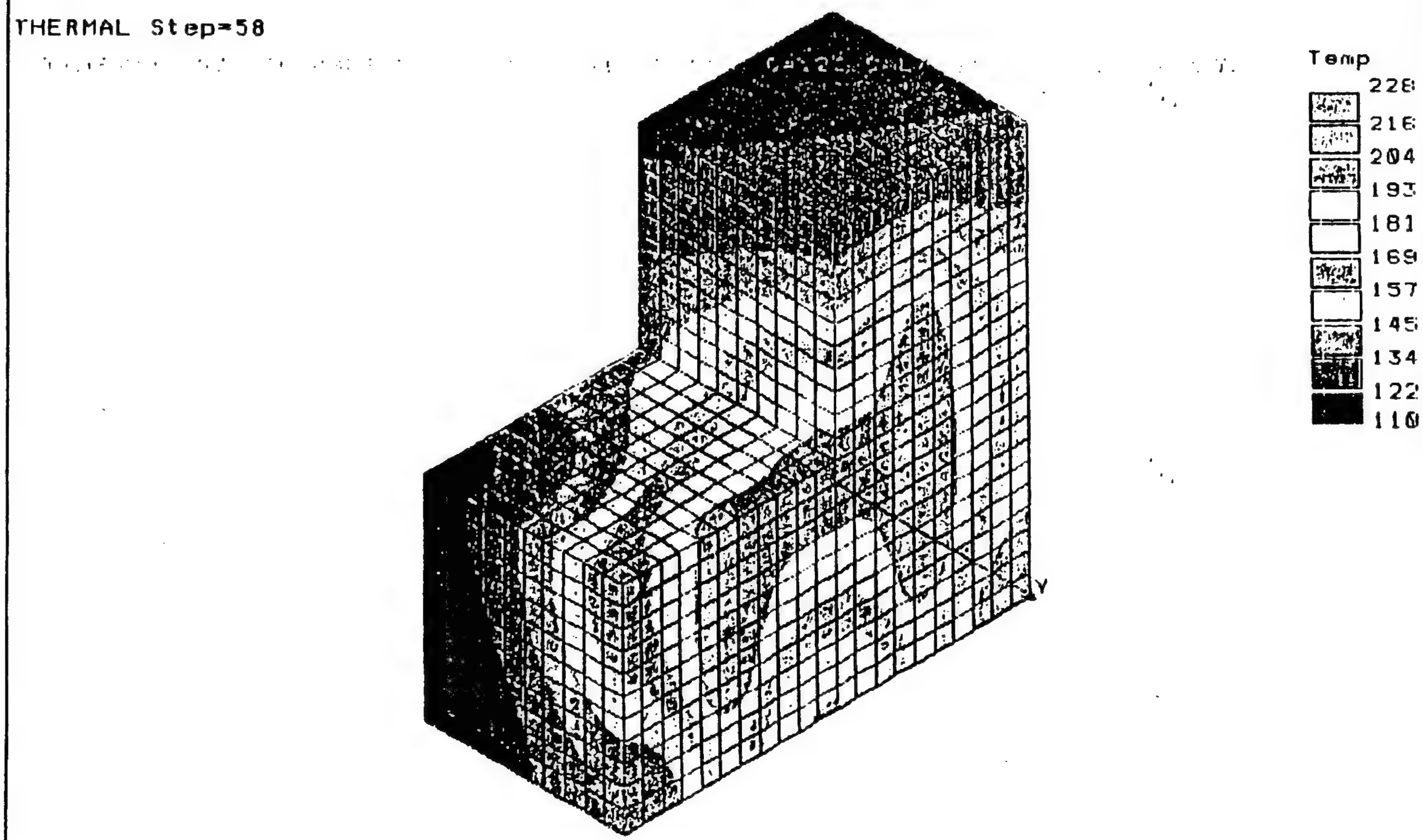
SGL.G05 **Single Applicator** Temperature Profile - After 15 days of RF heating



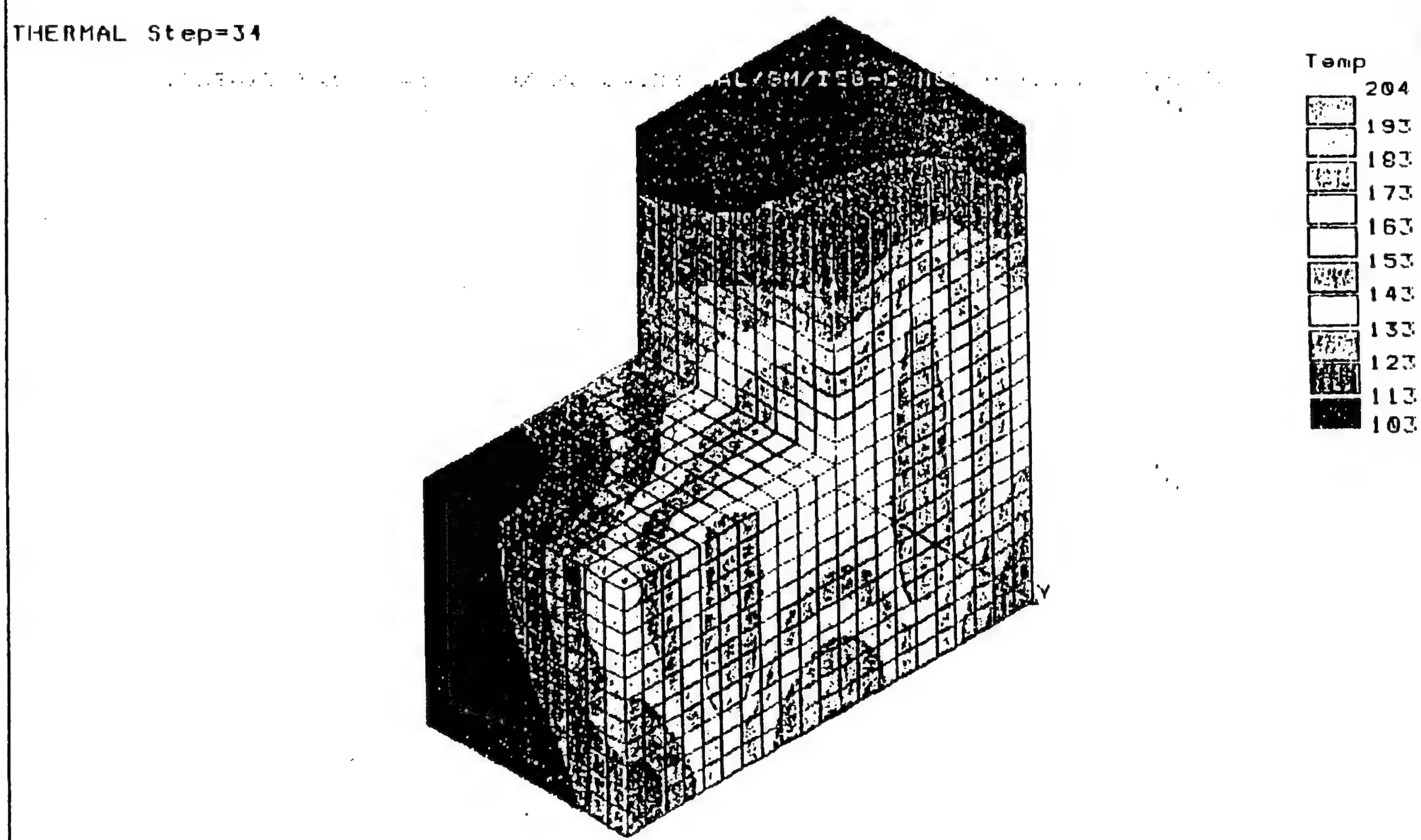
SGL.G07 **Single Applicator** Temperature Profile - After 27 days of RF heating



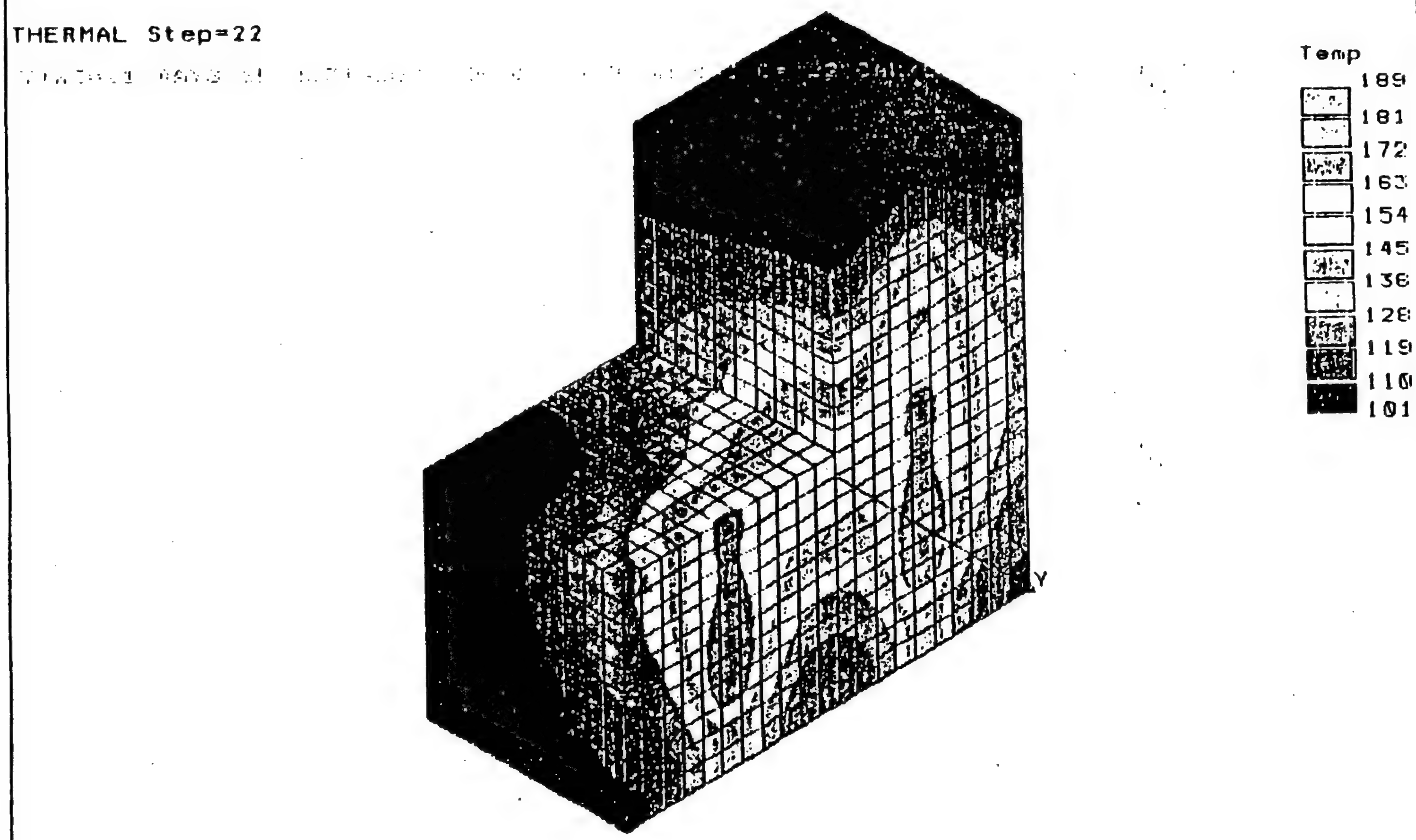
DBL.G09 **Dual applicators** Temperature Profile - After 0.5 days of RF heating



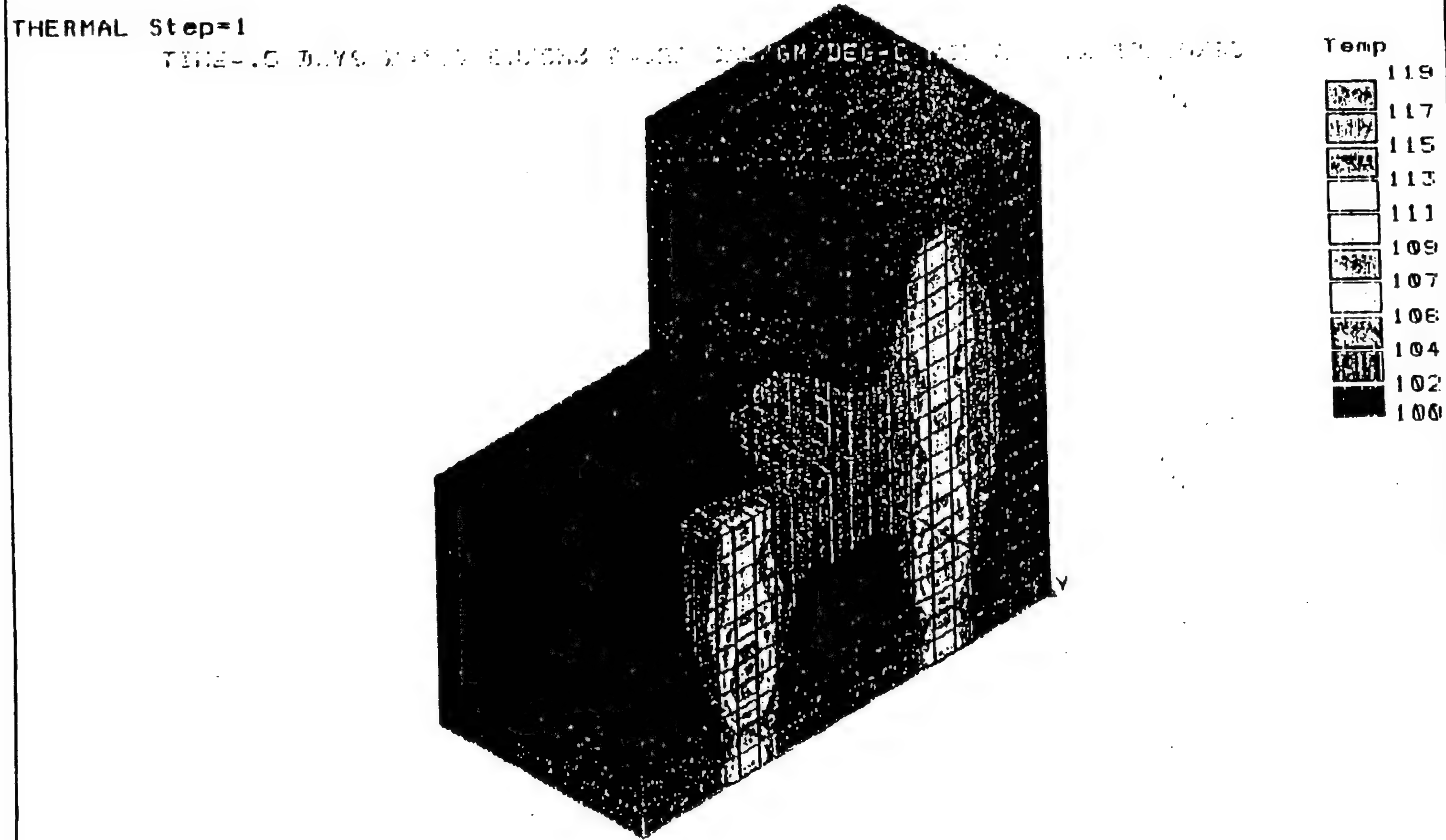
DBL.G07 **Dual Applicators** Temperature Profile - After 29 days of RF heating



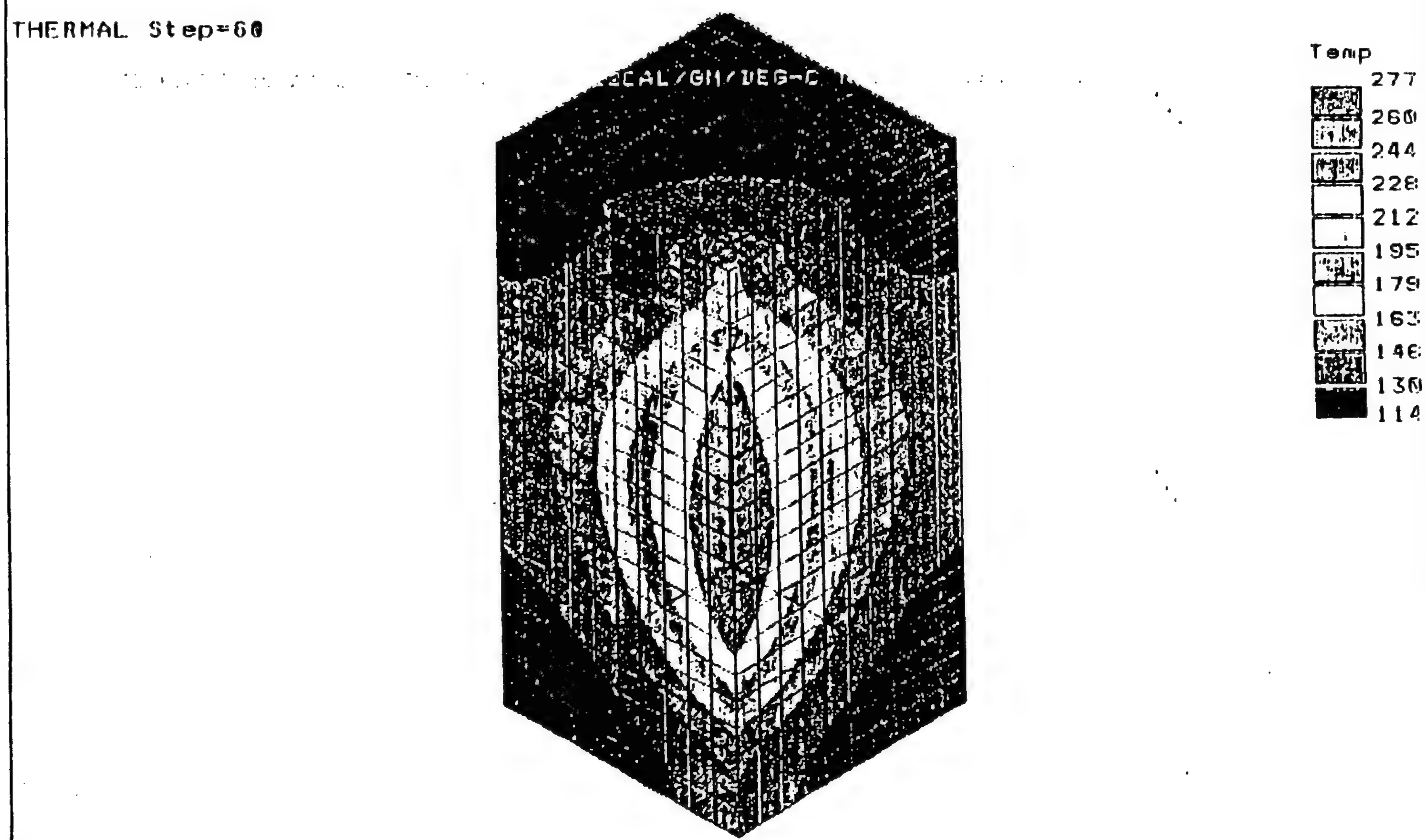
DBL.G05 **Dual Applicators** Temperature Profile - After 17 days of RF heating



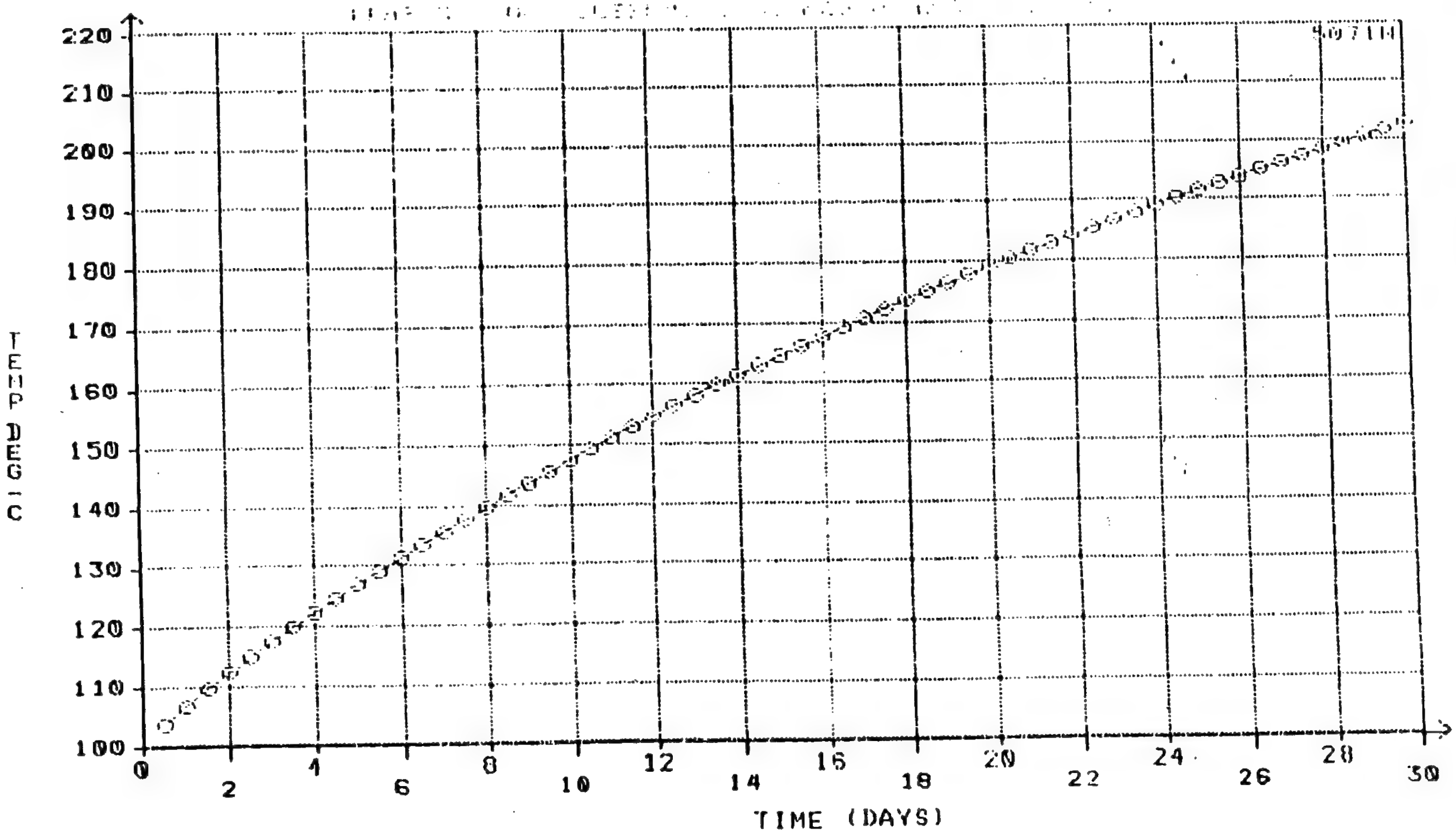
DBL.G04 **Dual Applicators** Temperature Profile - After 11 days of RF heating



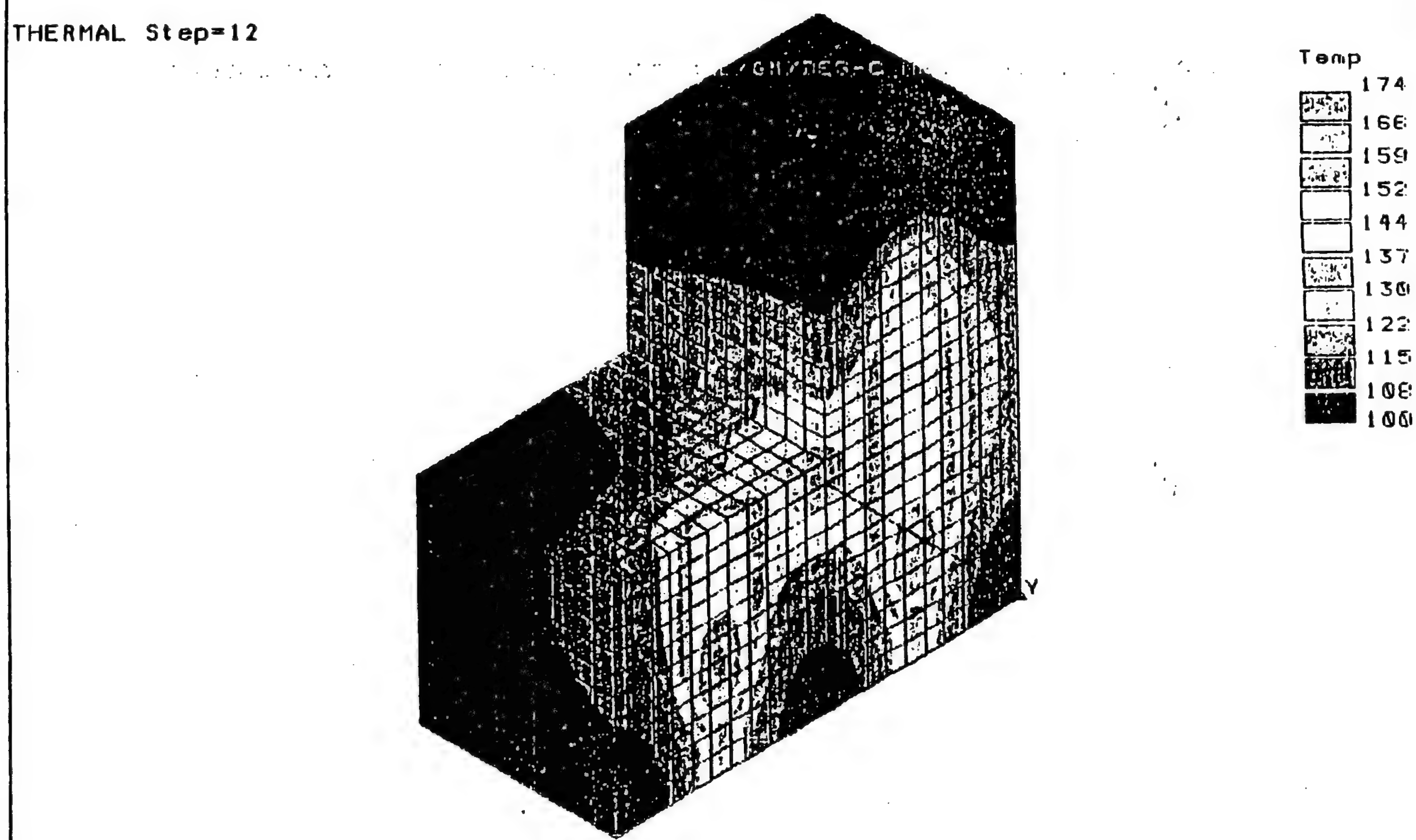
DBL.G02 **Dual applicators** Temperature Profile - After 0.5 days of RF heating



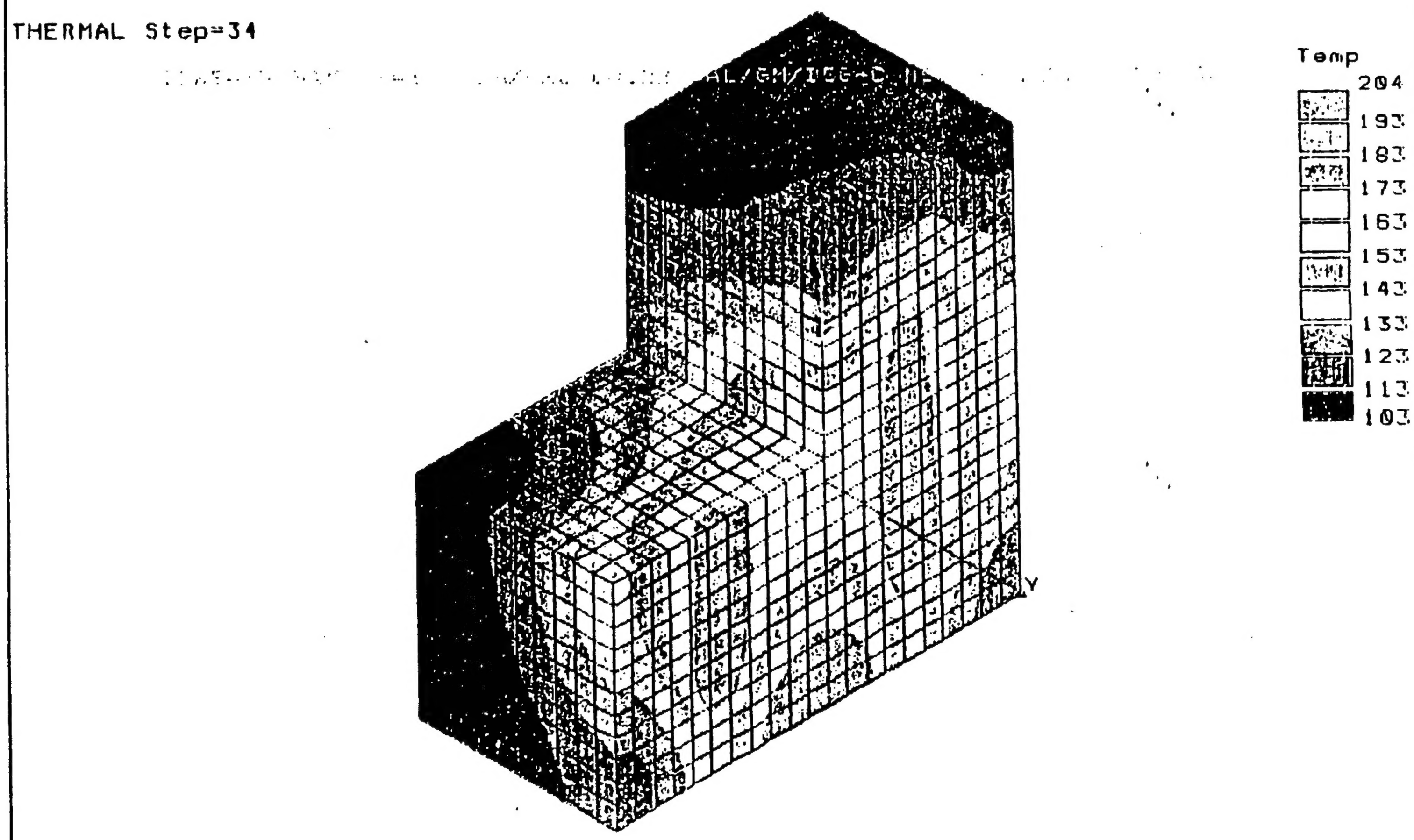
SGL.G08 **Single Applicator** Temperature Profile - After 30 days of RF heating



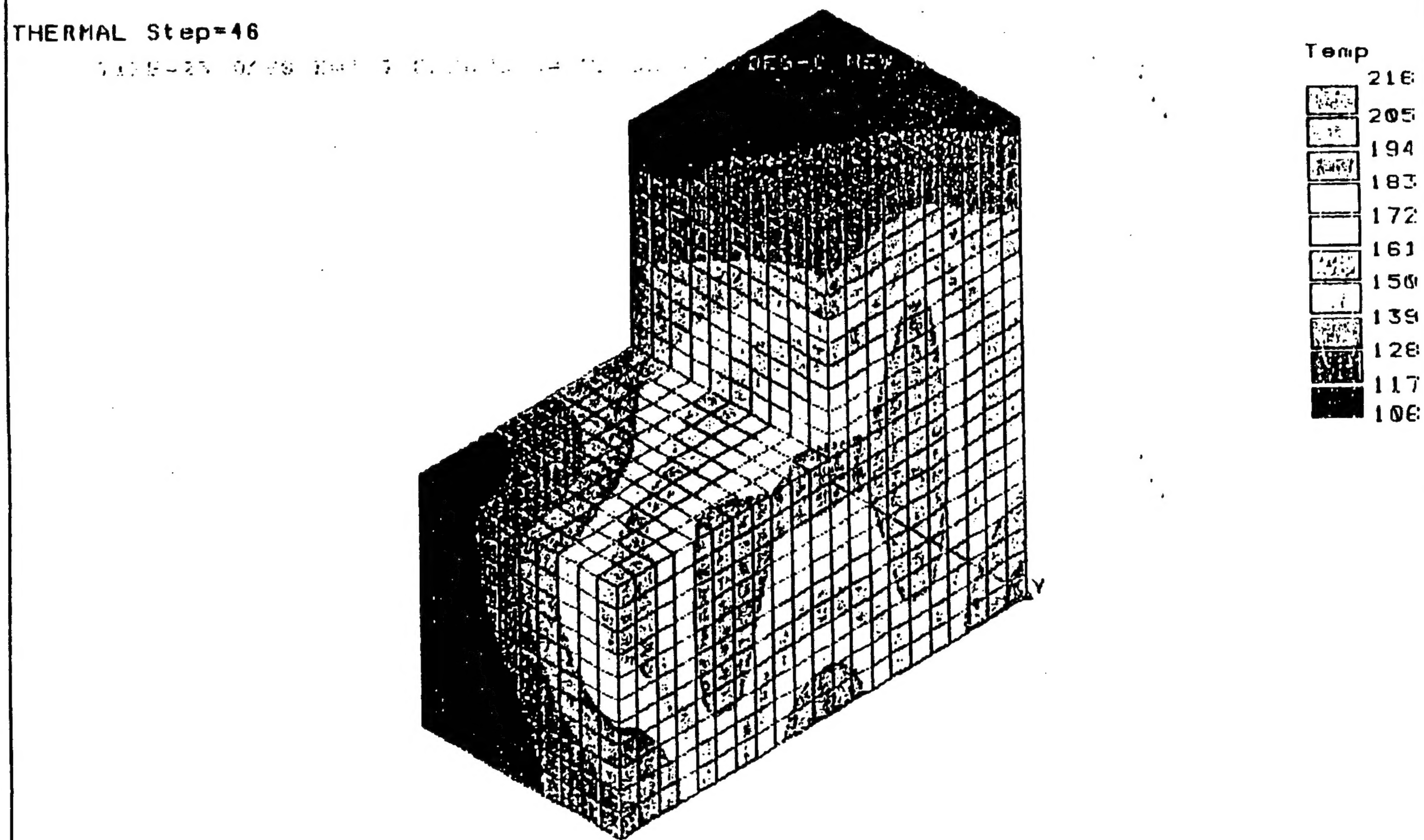
DBL.G01 **Dual Applicators** Temperature vs. Time - 5' radially away from feed



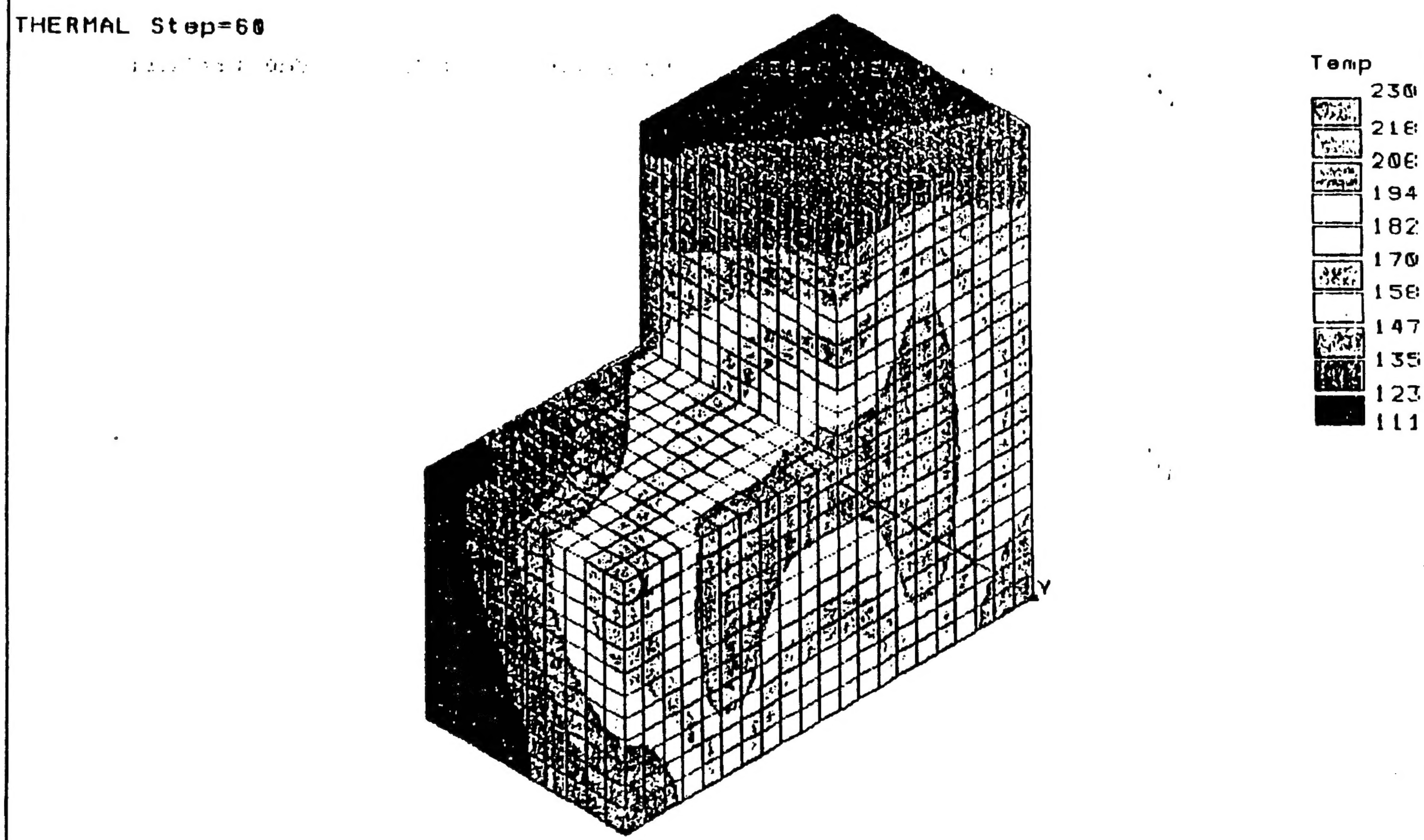
DBL.G03 **Dual Applicators** Temperature Profile - After 6 days of RF heating



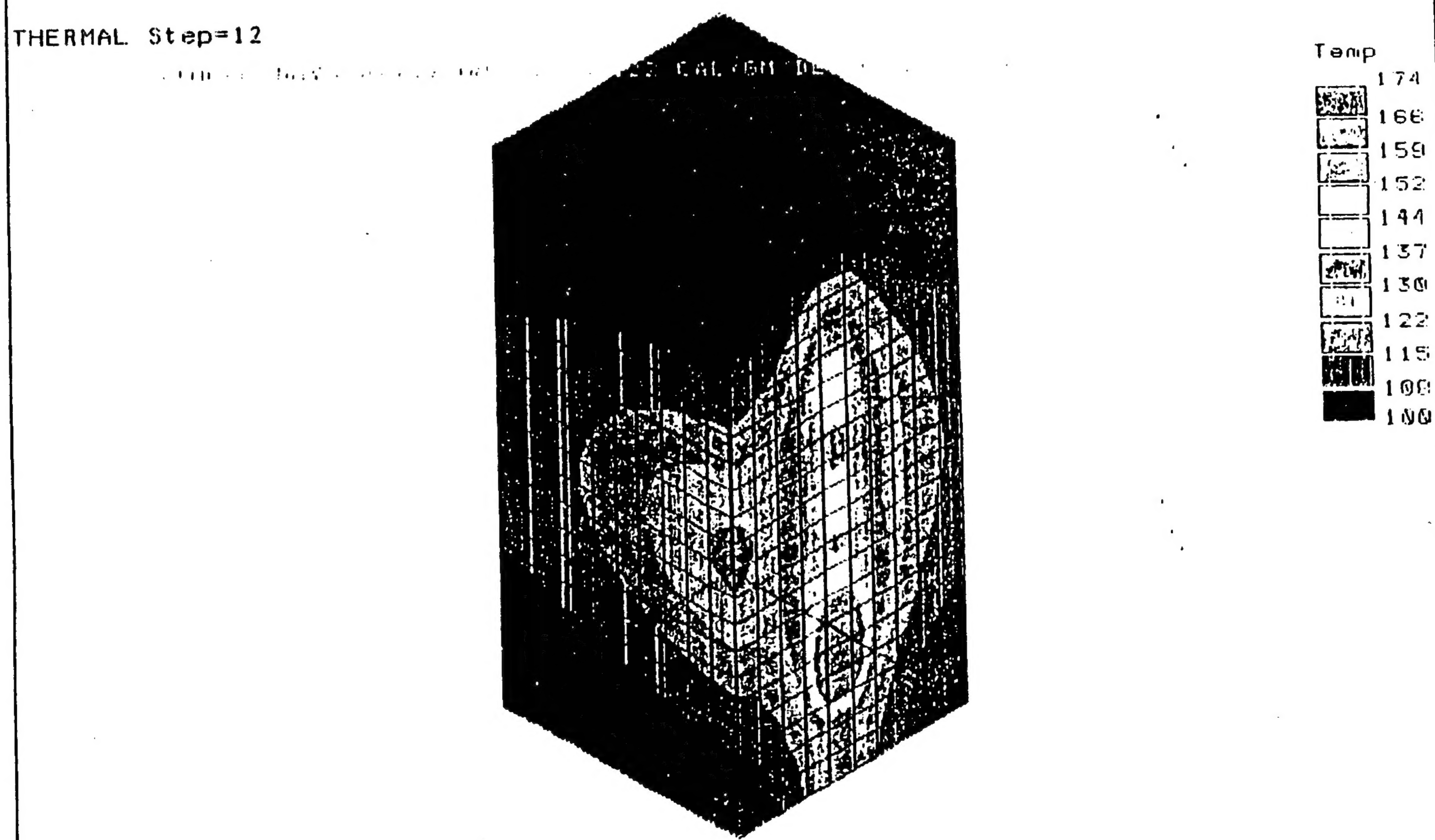
DBL.G05 **Dual Applicators Temperature Profile - After 17 days of RF heating**



DBL.G06 **Dual Applicators** Temperature Profile - After 23 days of RF heating



DBL.G08 **Dual Applicators** Temperature Profile - After 30 days of RF heating



DBL.G10 **Dual Applicators** Temperature Profile - After 6 days of RF heating

G10